Review of Salmon Transplant Procedures and Suggested Transplant Guidelines

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A.Y. Fedorenko and B.G. Shepherd

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ABSTRACT

Fedorenko, A.Y., and B.G. Shepherd. 1986. Review of salmon transplant procedures and suggested transplant guidelines. Can. Tech. Rep. Fish Aquat. Sci. 1479 : 144 p.

This report reviews the available literature on successful salmon transplants worldwide, with emphasis on chinook and sockeye. The information was used to develop a set of transplant guidelines for establishing both artificially-maintained and naturally-maintained stocks. Three major areas were explored: selection of suitable donor stocks, selection of suitable receiving sites, and the use of appropriate fish culture and release strategies. For developing artificially-maintained stocks, the key requirements for donor stocks include geographical proximity, good access and infrastructure, suitable disease profiles and sufficient escapements. The key requirements for receiving sites include isolation from wild stocks, good access to release sites, and suitable infrastructure, marine environment and terminal fishery sites. Key fish culture methods and release strategies involve large-scale (minimum 1 million eggs/yr) and long-term (up to 10 yr) outplants, large gene pool (a minimum of three donor stocks and their hybrids), appropriate size and timing at release, use of techniques for improved homing, and nurturing of transplant progeny. Feasibility and assessment studies, at a level adequate to define reasons for success or failure of the project, are also recommended.

RÉSUMÉ

Fedorenko, A.Y., and B.G. Shepherd. 1986. Review of salmon transplant procedures and suggested transplant guidelines. Can. Tech. Rep. Fish. Aquat. Sci. 1479 : 144 p.

Le présent rapport passe en revue la documentation disponible sur les transplantations de saumon réussies un peu partout dans le monde et plus particulièrement sur les transplantations de saumon quinnat et de saumon rouge. L'information recueillie a été utilisée afin d'élaborer des lignes directrices sur les transplantations visant à établir des stocks maintenus de façon artificielle ou naturelle. Trois grands points ont été examinés, soit: la sélection de stocks de donneurs appropriés, la sélection de milieux d'introduction appropriés et l'utilisation de méthodes d'élevage et d'introduction appropriées. Pour constituer des stocks maintenus artificiellement, les principales exigences à respecter pour les stocks de donneurs comprennent la proximité géographique, l'accessibilité et une bonne infrastructure, le choix de sujets ne présentant aucune maladie ainsi que des conditions permettant les échappées. Les principaux facteurs a considérer pour les milieux d'intorduction sont l'isolement d'avec les stocks sauvages, l'accessibilité aux sites d'introduction, une bonne infrastructure, un environnement marin et des sites de pêche en estuaire convenables. Les principales méthodes d'élevage et d'introduction de poissons supposent des activités a grande échelle (minimum de 1 million d'oeufs/année) et à long terme (jusqu'à 10 ans), un effectif des gènes important (minimum de trois stocks de donneurs et leurs hybrides), le choix d'une taille et d'un âge appropriés pour l'introduction dans le cours d'eau, l'utilisation de techniques pour améliorer les remontes et les conditions d'élevage de la progéniture. On recommande d'effectuer des études de faisabilité et des évaluations pour déterminer les raisons du succès ou de l'échec du projet.

INTRODUCTION

THE NEW FISHERY DEVELOPMENT PROJECT CONCEPT

The artificial incubation and rearing of salmon and the release of juveniles for subsequent ocean rearing have been practised extensively in North America, Japan and Europe for many decades. The major goal of most hatchery programs has been to enhance and restore depleted salmon stocks in the face of severe habitat degradation and fishery exploitation.

One of the major, long-recognized dilemmas related to hatchery operations has been the indiscriminatory harvesting by offshore fisheries of both enhanced and unenhanced stocks with consequent overfishing of less abundant wild stocks. Selective interception of enhanced runs in an isolated terminal fishery would be one solution to this problem. With this in mind, the Salmonid Enhancement Program (SEP) of the Department of Fisheries and Oceans (DFO) is considering a proposal to transplant appropriate donor stocks of salmon to selected B.C. watersheds currently barren or greatly underutilized by these species. Emphasis is likely to be placed on chinook and sockeye as these are two most commercially valuable Pacific salmon species. A number of candidate sites were identified as part of the stock rebuilding exercise (Table 1). Large releases of hatchery-produced juveniles would be made annually at the selected release sites with subsequent harvesting of returning adults in an entirely new terminal fishery. An additional benefit of the transplant programs would be the colonization of any unused salmonid habitat in the receiving area.

PREVIOUS TRANSPLANT STUDIES

Numerous transplant attempts involving Pacific salmon have been undertaken since the 1800s. These attempts, generally aimed at establishing natural self-propagating runs in depleted or barren areas, have failed in most cases (Ricker 1972; Aro 1979; Withler 1982). Such transplants require very careful consideration of genetic and environmental variables when selecting the donor stocks in order to ensure the natural reproductive success of the transplanted fish and their progeny in the new environment. If stock characteristics do not meet the environmental demands closely, the ability of donor stocks to adapt to a new environment would be a risky and slow process, especially without the assistance of artificial propagation to develop the broodstock. Withler (1982) reviewed Pacific salmon transplants and observed that several naturally self-sustaining runs have been established by colonizing outside the native range; for example, chinook in New Zealand; pink, coho and chinook in the Great Lakes; and pink salmon in the USSR. In contrast, the Lake Washington sockeye transplant is the only record of a successful transplant within the native range of Pacific salmon, except in cases where an obvious physical barrier prevented fish access.

The early transplant failures were often the result of a general lack of understanding of the principles governing transplant biology and the lack of fish culture knowledge and experience (Zimmer et al. 1963). For example, donor stocks often were selected on the basis of availability of surplus eggs rather than on biological and physical compatibility with the recipient site (Dept. Fish. Canada MS 1966). Also, most of the early transplant programs were poorly

Table 1. List of candidate sites proposed as new Fishery Development projects.

Proj. No.[a]	Name of Site(s)	Lat	Long	Description/Comments
2WD	Van Inlet	53° 16'	132° 34'	West coast of QCI (Graham I); Road access, potential headwater lake, gravity-feed water supply. Area may be subject to storms hindering the use of seapens. No local stocks.
5-3D	Batchellor Lk Red Bluff Lk Sylvia Lk Wyndham Lk	53° 36' 53° 28' 53° 31' 53° 36'	129° 40' 129° 36' 129° 37' 129° 46'	Area 5 'Hanging Lakes' near tidewater may be suitable for outplanting of coho or sockeye fry.
6-16A	Butedale	53° 09'	128° 42'	Old fish cannery/freezer facility, presently used in part as sport fishing lodge. Headwater lake, gravity-feed water and power supply in place. Lake outplanting as well as seapens possible. Owner interested in aquaculture.
	Deer-Bear-Cougar Lks (Surf Inlet)	52° 12'	129° 01'	Abandoned high concrete dam at tidewater gives headwater lake, gravity-feed potential and outplanting potential.
	Whalen Lk	53° 12'	128° 55'	Natural hanging lake at tidewater. Logging road access from mouth to lake outlet. Outplanting and gravity-feed water supply potential.
	Yule Lk	53° 02'	128° 27'	Abandoned pulp mill (first one constructed in B.C.). Headwater lake, gravity-feed potential and outplanting potential.
8-3B	Ocean Falls	52° 00'	127° 30'	Potential to use abandoned pulp mill/dam/power facilities. Existing community. Lake may have outplanting potential.
8-4	Namu	51° 52'	127° 52'	Existing cannery structures may have potential for fishculture.
9-16	Sandell Lk	51° 34'	127° 27'	Good Hope Cannery, now sport fishing lodge. Potential to develop project jointly with lodge operators. Excellent lake outplanting, seapen and gravity-feed water supply potentials.

[a] Project number as per Lill et al. (MS 1985).

documented and assessed, and the results often were confounded by the existence of residual native runs in the recipient system (Ricker 1972; Withler 1982). Withler (1982) stated that while the causes for the numerous transplant failures were unclear, the major problems may have been insufficient magnitude and persistence of transplanting, inadequate techniques, and biological inadequacies such as unfavourable temperatures, low food supply, excessive predation and poor homing cues. Whatever the causes, the failure rate has been so high for transplants that the lack of success has become the focus (eg. Withler 1982), rather than a learning experience as to what makes some transplants successful.

A number of studies relating to the information needs for transplants have now progressed to the point that formulation of guidelines can be attempted. The guidelines proposed in this report result from a review which emphasized both successful transplant experiences and the use of artificial propagation in improving transplant success.

METHODS AND DEFINITIONS

This report reviews currently available information on the more successful salmon transplants worldwide, with emphasis on chinook and sockeye. The information was gathered through literature survey, telephone interviews and written requests submitted to selected fishery biologists in Canada and the United States. Where the correspondence failed to yield results, a telephone follow-up was conducted. The surveyed biologists provided information on transplant activities in their area, personal interpretation of results, additional published and unpublished data sources and further contacts. The successful transplant activities, detailed in the appendices to the report, allowed the authors to develop a set of guidelines for successful salmon transplants discussed in the body of the text. Due to the considerable relevant information on transplants of salmon species other than chinook and sockeye, a multi-species approach was adopted whereby it was assumed that a transplant criterion developed for one species may also benefit the transplant of another species.

The terms "stock" and "race" used in this report are synonymous and are based on Ricker's (1972) definition where a stock refers to a group of salmon of the same species which spawn at a certain time of year in a particular body of water, with little or no interbreeding with other groups. Many medium and large rivers have more than one stock. A "run" within a river may consist of several stocks that have similar migration timing.

The term "transplant", as used in this report, is defined as a transfer of fish by man outside the stock's current range. The transplant procedure may or may not involve artificial propagation, and the receiving waters may contain representatives of that species. The term "colonize" is interchangeable with the term "transplant" but generally refers to the introduction of fish into a habitat previously unoccupied by that species or to the natural invasion of a stream through adult straying. The term "outplant" refers to transport of juveniles from a hatchery to natural rearing areas of systems within and outside that stock's present range. Throughout the report, distances between donor and recipient systems are measured between stream mouths along connecting bodies of water, unless otherwise stated.

THE ROLE OF HATCHERIES IN SUCCESSFUL SALMON TRANSPLANTS

Historically, the majority of salmon transplants consisted of relatively small-scale plantings (less than 0.5 million eggs or juveniles) which were generally discontinued after only a few years. Yet, even these modest efforts often produced some returns which could have been further nurtured through artificial propagation. Reviewing various successful transplants of salmon, it seems clear that hatcheries can be essential for developing and maintaining transplanted runs at least until a strong broodstock develops. The more notable examples include chinook transplants in Wind River (Appendix 8), sockeye transplants in Frazer Lake (Appendix 16) and Lake Washington (Appendix 17), and pink transplants in the northeastern USSR (Appendix 29). In these and other cases, hatchery production has led to successful acclimation of salmon to the recipient system. Where freshwater habitat is unsuitable or limited, hatchery outplanting has become a permanent tool in maintaining the transplanted run. Some specific examples demonstrating the importance of hatcheries in developing and maintaining salmon transplants are reviewed below.

In British Columbia, hatchery propagation has been important in developing chinook runs in the Capilano and Little Qualicum Rivers (Appendices 2 and 3) and sockeye runs in the Upper Adams River (Appendix 14), among others. In the Great Lakes, significant recreational fisheries on chinook and coho, successfully introduced there in the 1960s and 1970s, are partially maintained by hatchery propagation (Appendices 5 and 22). Hatcheries such as Samish, Minter Creek, and Issaquah are used for maintaining transplanted Green River chinook introduced into barren streams in Puget Sound (Dept. Fish. Canada MS 1966). In general, fish introductions in Washington State indicate that chinook transplants may be very successful when combined with hatchery propagation (Dept. Fish. Canada MS 1966). Recent coho transplants in New Hampshire are totally dependent on hatchery production due to unsuitable freshwater environment for natural propagation (Appendix 24). In Alaska, programs are being developed for large-scale hatchery production of coho fry for stocking in lakes with outlet barrier falls (Crone 1981). Returning adults will be artificially spawned in hatcheries and the resultant fry restocked annually (FFI 1975b). Hatcheries are also widely used for reestablishing runs of Atlantic salmon in the Atlantic regions of Canada and the United States, where this species has been nearly eliminated (Saunders 1981).

Outside the North American continent, hatcheries are used extensively in the USSR to maintain the pink salmon populations introduced in the Kola Peninsula (Withler 1982). In New Zealand, hatchery propagation is critical for enhancing introduced chinook runs to support a commercial fishery (Anon. 1983). Introduced chum, coho and chinook stocks are intensively cultured in salmon ranching ventures in Chile (FFI 1983, 1984c; Hopkins 1985). In the Faroe Islands, located between Iceland and Scotland, Atlantic salmon originally transplanted from Iceland are maintained with hatchery outplants of fry, using the returning progeny as broodstock (FFI 1984d).

TRANSPLANT GUIDELINES

The following sections deal with transplant guidelines used for developing both naturally-sustained runs and hatchery-propagated runs. The transplant guidelines are discussed under three major headings: (A) selection of donor stocks, (B) selection of receiving sites, and (C) use of appropriate fish culture methods and release strategies.

Only partial emphasis was placed on guidelines for selecting the most suitable donor stocks since in many of the reviewed transplant activities, the donor stocks were selected largely on the basis of the availability of surplus eggs. Rarely was there any specific matching of selected features conducted between the donor stock and the recipient site. Also, in the few cases where transplants succeeded, the key donor stock characteristics related to transplant success remained vague, as in the chinook transplants in New Zealand. Thus, no clear evidence was obtained that donor stock characteristics alone have ever determined transplant success. Rather, a combination of factors was apparently responsible for the success, including characteristics of donor stocks and of recipient sites, as well as propagation and planting techniques.

A. SELECTION OF DONOR STOCKS

The donor stock characteristics that should be considered in transplant programs are discussed in the following seven sections.

A.1. GEOGRAPHICAL PROXIMITY

Thorpe (1980) noted that although transplants over long distances have proved successful in some instances, more often the transplanted stocks failed to adapt to the new environment. The benefits of using geographically close donor stocks for salmon transplants have been widely observed. The primary benefit is perceived to be a greater biological suitability of the nearby donor stock to the new site compared to a more distant stock (Reisenbichler and McIntyre MS 1986; D. Ortman, pers. comm.). Geographically close river systems often have similar environments so that better adaptibility may be expected from local transplants. Other benefits noted include reduced negative effects from interbreeding with neighbouring wild stocks since straying within a certain range is a natural phenomenon, and reduced hazards of spreading foreign diseases to the new site since more similar disease profiles may be expected between geographically close salmon populations compared to distant populations. These observations have greatly affected recent transplant activities; for example, in Idaho, the selection of geographically close donor stock is recommended in salmonid stock transfer guidelines (Howell et al. 1985b), and in Alaska salmon transplants are generally limited to within 80 km of the donor site (K. Johnson, pers. comm).

The importance of selecting geographically close donor stocks for colonization of new areas is reviewed below for each species.

Chinook

Although some chinook transplants over great distances have succeeded (eg. the New Zealand and Great Lakes), most successful chinook transplants have used a donor stock from a geographically close stream such as transplants to the Capilano River (108 km between donor and recipient streams; Appendix 2) and the Little Qualicum River (9 km between donor and recipient streams; Appendix 3), or from within the same watershed such as transplants to the Wind River (16 km between donor and recipient streams; Appendix 8) and Willamette River (60 km between donor and recipient streams; Appendix 9). Ricker (1972) noted that transfers of chinook fingerlings were up to 10 times more successful in terms of adult returns for streams within Puget Sound, as in the case of the Green River chinook transfer to Deschutes River (94 km between donor and recipient streams; Fig. 1), compared to more distant transfers such as the Little White Salmon River chinook transfer to Deschutes River (730 km between donor and recipient streams; Fig. 1), or the Green River chinook transfers to Washington coastal streams. Based on experiences with chinook transplants in Idaho, Ortman (pers. comm.) observed that better adaptation and homing may be expected if geographically close donor stocks of chinook were selected, preferably from the same watershed.

Reisenbichler and McIntyre (MS 1986) studied genetic profiles of chinook populations and concluded that for successful transplants, genetically similar broodstock from nearby streams should be used. The above authors gave an example of genetic structuring among the spring-run chinook populations in the Columbia River system, developed from isozyme frequency data (Milner et al. MS 1980). Three distinct groups of chinook salmon are found in the Columbia basin (Fig. 2), coinciding with the occurrence of two major geographic features—the Columbia Gorge where the Columbia River passes through the Cascade Mountains, and Hell's Canyon where the Snake River passes through a westward extension of the Rocky Mountains. Reisenbichler and McIntyre (MS 1986) suggested that when such genetic structuring is apparent in a system, intergroup transfer of fish should be avoided due to gene isolation between groups and possible different adaptations to distinct environmental conditions. If such transfers are made, reduced survival may be expected at least initially and distinct genetic systems may be disrupted. They further suggested that where non-indigenous stocks are transplanted and where genetically similar populations cannot be identified, the initial broodstock should be selected from a geographically close population, as measured along connecting bodies of water.

Sockeye

For transplants involving sockeye salmon, colonization success as measured by adult returns, has been much higher for short-distance compared to long-distance transfers (Ricker 1972). Among the successful sockeye transplants reviewed, Frazer Lake sockeye originated from nearby Red Lake donor stock (80 km between donor and recipient streams; Appendix 16), Washington Lake sockeye originated from the Skagit system some 70 km to the north (Appendix 17), and Great Central Lake sockeye on Vancouver Island were enhanced using Henderson Lake donor stock located about 60 km from the recipient system (Appendix 15). Also, the recent returns of sockeye (3,502 adults in 1984) to the Upper Adams River were attributed in part to the use of nearby Momich-Cayenne donor stock (13 km between donor and recipient streams; Appendix 14).

Coho

In Alaska, a geographically close donor stock (3-5 km from recipient stream) was used for stocking of "barrier" lakes with coho juveniles (Heard 1978). In Oregon, the selection of the closest available donor stock is one of the major guidelines used in recent coho transplants (T. Nickelson, pers. comm.). Coho survival data from transplants of hatchery populations within the Columbia River basin clearly show the importance of geographical proximity of donor stocks in determining transplant success (Reisenbichler and McIntyre MS 1986). Among coho transferred from one hatchery to another as eyed eggs and

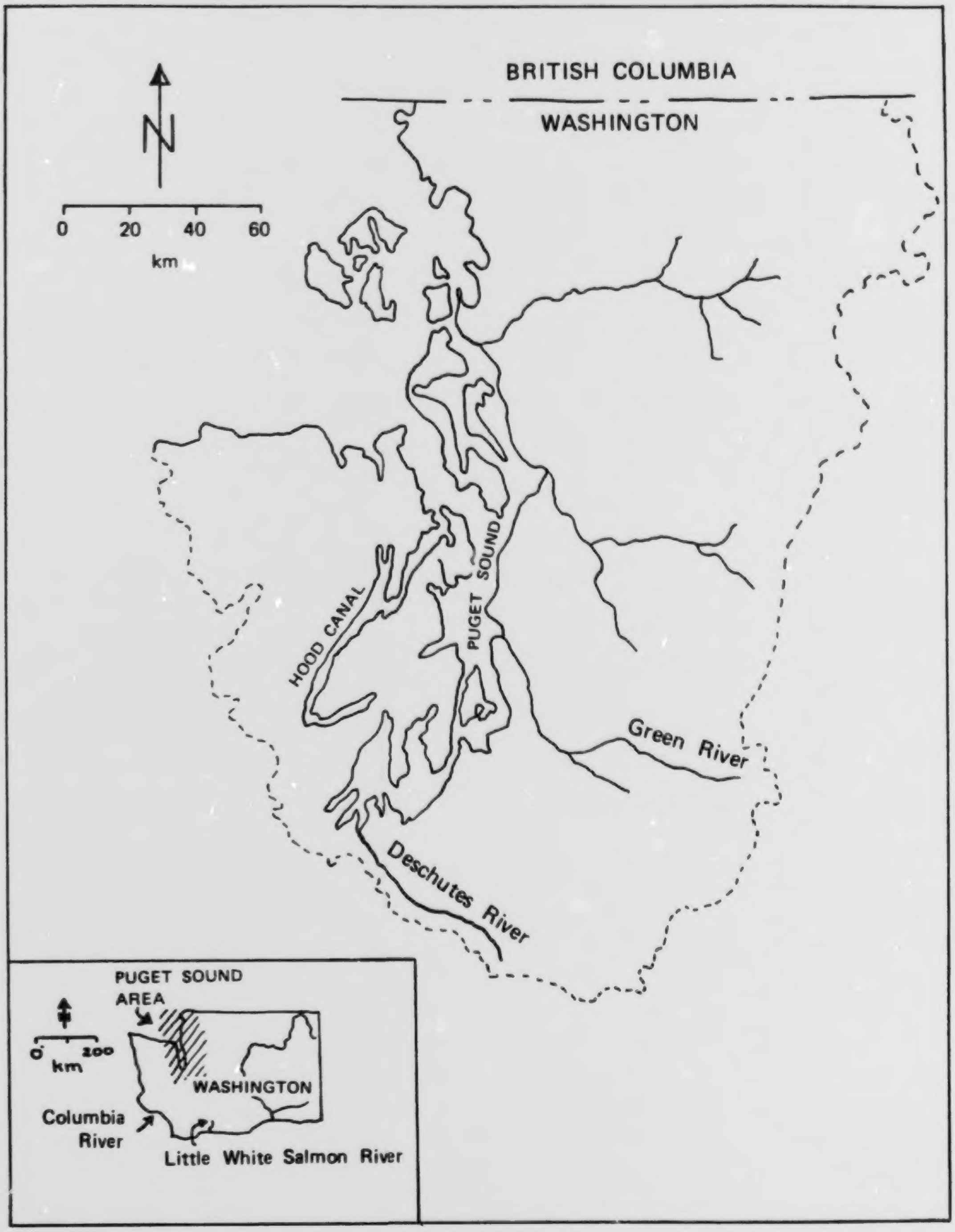
BRITISH COLUMBIA
WASHINGTON
N
0
20
40
60
km
HOOD CANAL
PUGET SOUND
Green River
Deschutes River
PUGET SOUND AREA
0
200
km
WASHINGTON
Columbia River
Little White Salmon River

Fig. 1. Location of Green River and Deschutes River in Puget Sound, and of Little White Salmon River in the Columbia River basin.

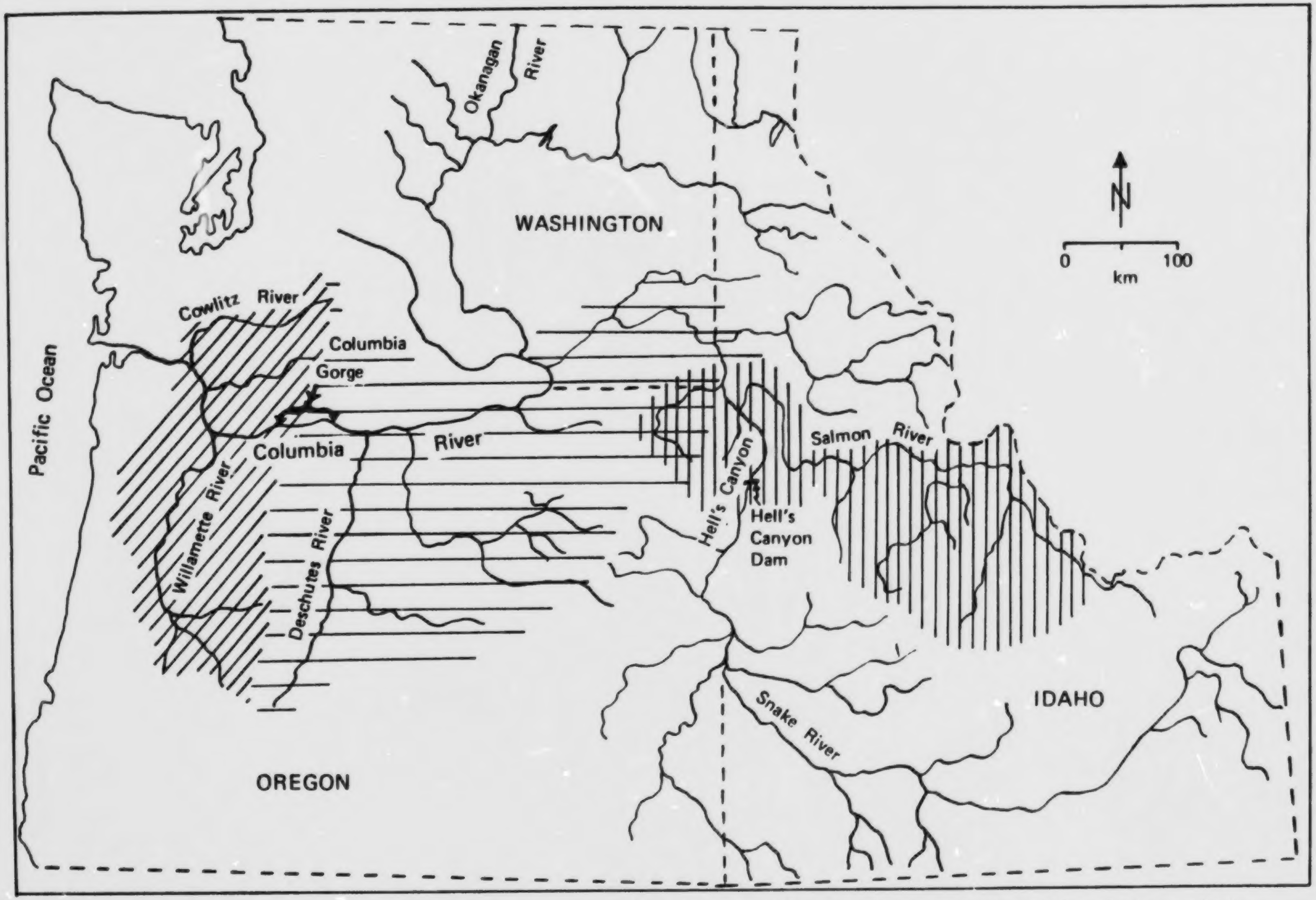
Pacific Ocean
WASHINGTON
OREGON
IDAHO
Okanagan River
Cowlitz River
Columbia Gorge
Columbia River
Columbia
Willamette River
Deschutes River
Hell's Canyon
Hell's Canyon Dam
Salmon River
Snake River
N
0
100
km

Fig. 2. Columbia River system showing three groups of spring-run chinook salmon as indicated by cluster analysis on allele frequencies from nine variant isozyme systems (from Reisenbichler and McIntyre MS 1986).

subsequently released as yearlings, returns were highest for those fish transferred the shortest distance (Fig. 3). Survival was reduced considerably at transplant distances beyond 100 km from the parental site, as measured along connecting bodies of water.

Atlantic salmon

In his studies on Atlantic salmon, Møller (1970) suggested that a local donor stock will be better adapted to the new environment than a more distant donor stock. Saunders and Bailey (1980) found that Atlantic salmon transplants in Maine rivers were more successful when local stocks were used as opposed to foreign stocks. For example, smolt releases into Penobscot River using New Brunswick's Miramichi River donor stock, located approximately 1,400 km away from the recipient site, gave few adult returns. In comparison, smolt releases into Penobscot River using residual stocks from Naraguagus and Machias Rivers located approximately 120 km and 190 km respectively from the recipient stream, resulted in a successful establishment of a hatchery-assisted run. Ritter (1975) observed that hatchery-reared Atlantic salmon smolts released in non-native rivers in New Brunswick and Nova Scotia showed a gradual decline in adult returns with increasing distance from native rivers. Thus, tagged hatchery smolts from the 1968 brood Restigouche River stock, released into progressively more distant Miramichi, West and Big Salmon Rivers, showed the following adult recoveries from fisheries and escapement:

Recipient System	Distance from Restigouche River (donor system)	Rate of Adult Recovery per 1000 Smolts
Miramichi River	270 km	19.7
West River	770 km	4.5
Big Salmon River	1,340 km	0.0

He attributed the reduced success of more distant transplants to increased straying and subsequent mortality. He further suggested that ocean migration routes are heritable and stock specific, and that smolts transferred farthest from their native stream would have the greatest difficulty linking up with their natural migration routes.

Steelhead

Washington stock transfer guidelines for steelhead recommend that in transplanting non-indigenous stocks to a new site, donor fish should come from the closest watershed (Howell et al. 1985b). Similarly in Oregon, a major guideline used in transplanting summer-run steelhead in the Willamette River in the Columbia basin is the proximity of donor and recipient sites in order to get a better genetic and environmental match (D. Buchanan, pers. comm.) Thus, the donor eggs for this transplant originally came from the North Fork of the Washougal River, located about 30 km upstream of the Willamette River (Howell et al. 1985b).

We recommend that in transplanting salmon, donor stocks should originate from within 100 km of the recipient site as measured between mouths of systems

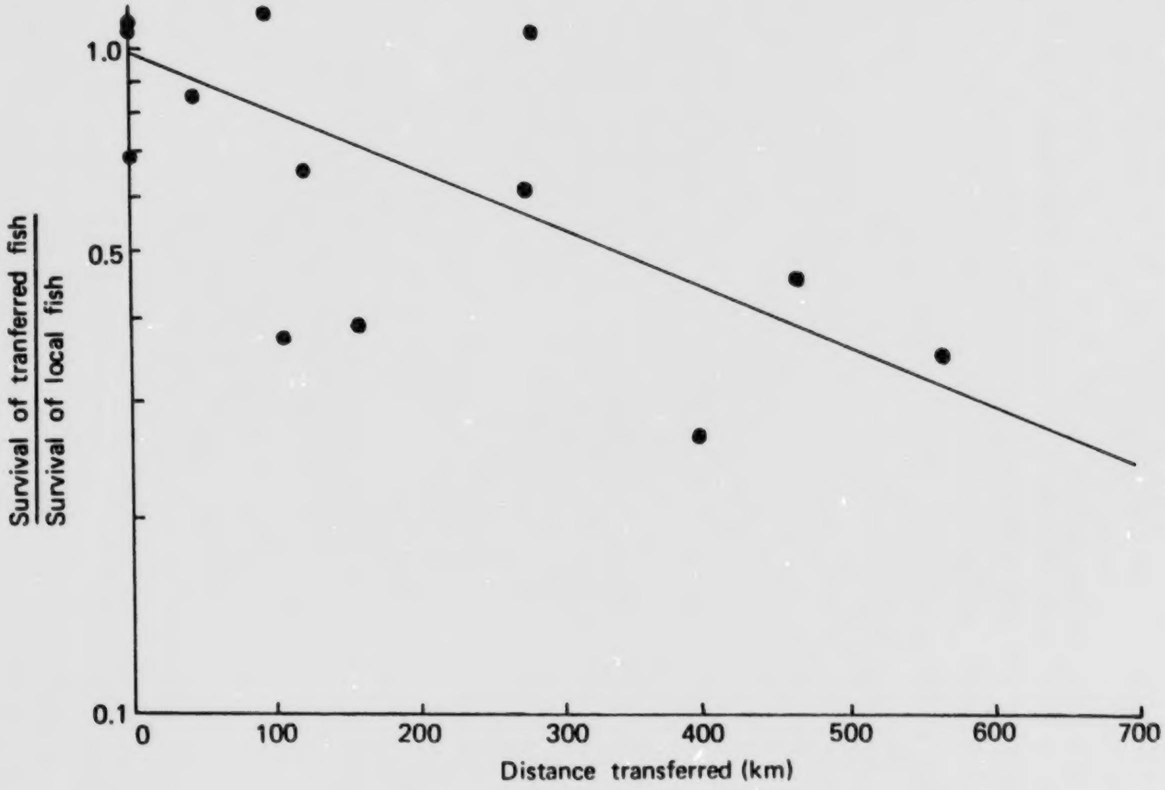

Fig. 3. Survival of transferred coho salmon divided by survival of local salmon reared in the same hatchery and released at the same time and location vs. distance between stream mouths (as measured along connecting bodies of water) for transferred and local stocks. Salmon were transferred as eyed eggs or larvae, the transferred and local fish were reared under similar conditions, and survival was from time of release (from Reisenbichler and McIntyre MS 1986).

along connecting bodies of water. Note that this form of measure is considered to be more acceptable biologically, compared to the use of a radial measure between systems, due to the general complexity of water routes between systems.

It should be cautioned that the geographic proximity is only one of many requirements for a successful transplant. Larkin (1981) stated that differences between stocks in a single river may be greater than differences between stocks in different rivers. An example is the Kenai River in Alaska which has two discrete chinook stocks that differ in migration and spawning timing and in river distribution (Burger et al. 1985). It was observed by A. McGie (pers. comm.) that chinook transplants to Coos River, Oregon, were more successful using the more distant Chetko River stock than the closer Elk River stock (Fig. 4). The importance of other factors is indicated also by the success of distant transplants such as the Sakhalin pink salmon in Kola Peninsula (about 9,500 km between donor and recipient streams; Appendix 29) and Columbia River coho in New Hampshire (about 12,000 km between donor and recipient streams; Appendix 24). This contrasts with the failed transplants using geographically closer donor stocks such as the Seymour River sockeye transplants into Upper Adams River (150 km between donor and recipient streams; Appendix 14), Tlell River pink salmon transplants into McClinton Creek on Queen Charlotte Islands (180 km between donor and recipient streams; Neave 1965; Dept. Fish. Canada MS 1966; Ricker 1972), and Cheakamus River pink salmon transplants into Qualicum River on Vancouver Island (120 km between donor and recipient streams; Walker and Lister 1971).

A.2. ACCESS TO BROODSTOCK

Physical accessibility of broodstock in the donor system can be an important cost and logistics factor for transplants, especially with long-term colonization efforts. Egg-take targets (see section A.3.) should not be placed at risk because of poor access. Availability of existing infrastructure such as roads, buildings, airstrips and power can lower costs considerably (Table 2).

A.3. BROODSTOCK ABUNDANCE

The selected donor stock should have sufficient escapement to withstand prolonged removal of broodstock for up to 10 years, in addition to the normal fishing pressure that it experiences. The minimum allowable escapement size of a potential wild donor stock in British Columbia is calculated below for chinook and sockeye.

Chinook

The following assumptions were made:

1. The sex ratio of the donor population is 50:50.
2. The mean fecundity of the donor stock is 5,000 eggs, based on the estimated fecundity of coastal British Columbia chinook stocks (Lill et al. MS 1985).
3. For purposes of robbing a donor stock to support a transplant, a 10% removal of annual escapement is recommended (30% is considered by SEP to be routine maximum in egg-takes when the parental stock is enhanced).

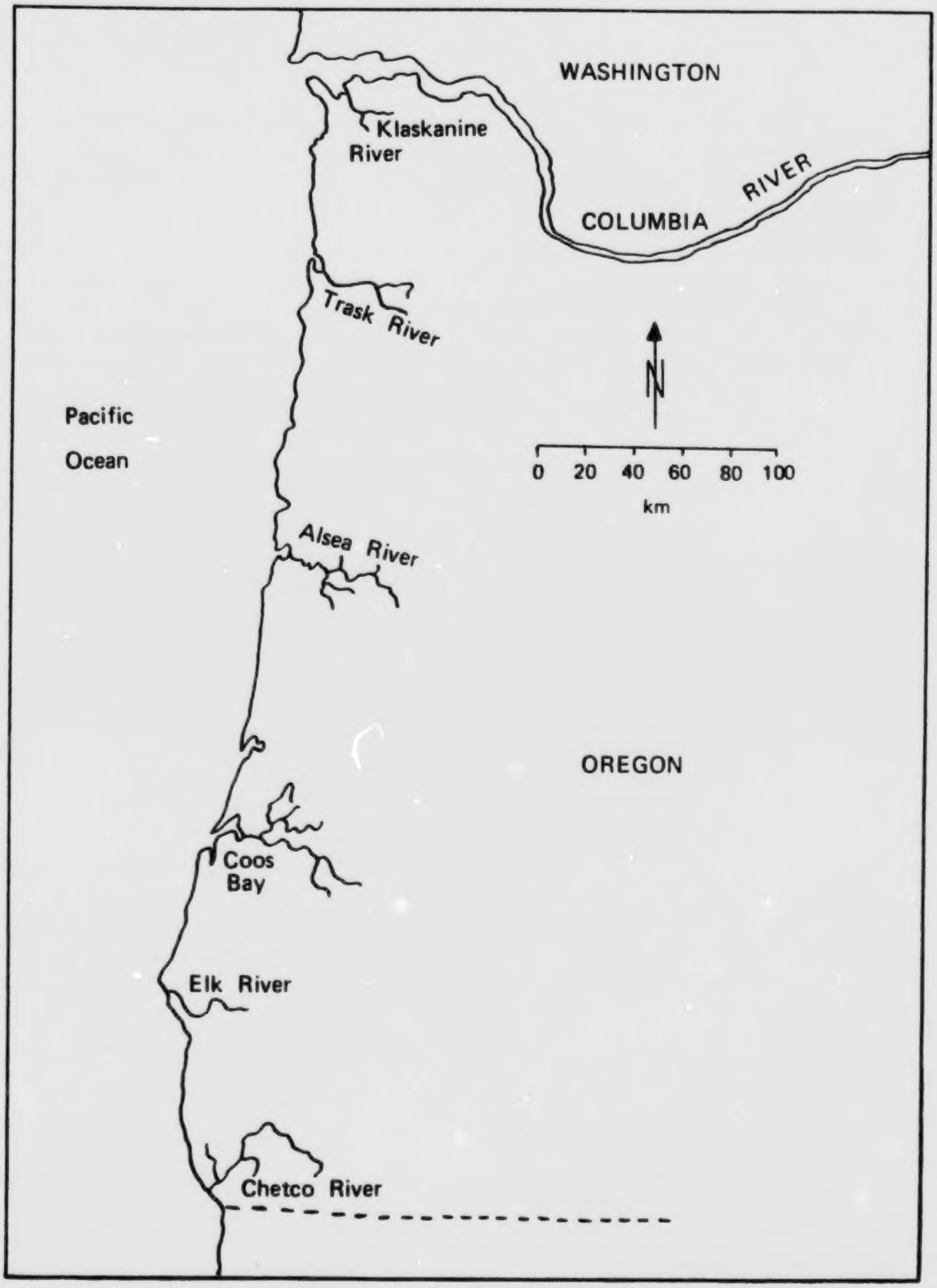
WASHINGTON
Klaskanine River
COLUMBIA RIVER
Trask River
N
0 20 40 60 80 100
km
Pacific Ocean
Alsea River
OREGON
Coos Bay
Elk River
Chetco River

Fig. 4. River systems selected for the coastal fall chinook stock assessment project (from McGie MS 1982).

Table 2. Infrastructure components to be considered when developing a transplant operation[a].

Resource activities in watershed (agriculture, logging, mining, industrial or urban development).

Location and type of human settlement (labor and logistical support potential).

Type and proximity of access to potential sites (presence of roads and airstrips, and size of water bodies suitable for landing with floatplanes).

Type and proximity of power.

---

[a] Modified from Shepherd (1984a).

4. A minimum of 1 million eggs must be available for annual transplants to the receiving site, at least initially (see section C.1).

5. A minimum of three donor stocks must be used for each transplant (see section C.2).

At a mean fecundity of 5,000 eggs/female, 200 donor females will provide the 1 million eggs required for the minimum annual transplant to the new site. This requirement translates into 67 females or 134 adults from each of the three donor stocks. If only 10% of the spawning run is allowed for transplant removal, each of the three donor stocks should have a minimum chinook escapement of 1,340 fish. If more than three donor stocks are used, the minimum escapement for each donor stock would be reduced accordingly. When considering abundance of donor stock, the most recent 10-year escapement average should be considered.

Sockeye

The same assumptions were made for sockeye as for chinook (see above), except that the mean fecundity of the donor stock was approximated at 3,000 eggs based on the estimated fecundity of coastal British Columbia sockeye stocks (Lill et al. MS 1985).

At a mean fecundity of 3,000 eggs/female, 333 donor females will provide the 1 million eggs required for the minimum annual transplant to the new site. This requirement translates into 111 females or 222 adults from each of the three donor stocks. If only 10% of the spawning run is allowed for transplant removal, each of the three donor stocks should have a minimum sockeye escapement of 2,220 fish. If more than three donor stocks are used, the minimum escapement for each donor stock would be reduced accordingly. When considering abundance of donor stock, the most recent 10-year escapement average should be considered.

A.4. BIOLOGICAL AND ENVIRONMENTAL CHARACTERISTICS

In selecting donor stocks for transplanting, the freshwater and marine conditions of the donor and recipient sites must be carefully matched in order to maximize the biological and environmental suitability of the donor stocks (Ricker 1954; Dept. Fish Canada MS 1966; Brannon MS 1970; Møller 1970; Joyner 1973; Lear 1975; Thorpe 1980; Anon. MS 1982). Where no long-term artificial propagation of the transplanted stock is planned, the selection of an appropriate freshwater environment for natural reproduction and rearing is essential. IPSFC (1966) stated that different runs of sockeye salmon, and even different races within the same run, vary widely in their tolerance to changes in spawning and incubation environment, with most populations being highly sensitive to such changes. The need for precise matching of environmental conditions becomes less critical if some of these conditions can be controlled artificially, as in hatchery propagation of coho transplants in the New Hampshire streams (Appendix 24).

Factors to be considered when matching biological and environmental characteristics between the donor stocks and the receiving site include the following:

A.4a. Matching life history types

The donor stock should have an appropriate life history type. Where no residual stocks exist in the recipient system, the suitability of migration and spawning timing of the donor stock may be based on comparable stream temperature regimes in the two systems. Wood and Riddell (MS 1985) noted that sockeye populations from the same watershed are more similar electrophoretically if they are of the same rearing type. For example, in the Stikine River watershed, three life history "rearing types" of sockeye are present: the "lake-type" and the "river-type" which rear for one to two years in lake and river respectively, and the "sea-type" which migrates directly to the sea after emergence. In this instance, transplanting an appropriate rearing type may be the deciding factor in the success of the operation. Since some uncertainty and flexibility exists in the life history of salmon such as sockeye and chinook, preliminary surveys should include sampling of donor sub-populations for a number of years if possible, to check for consistency in the age structure of these populations.

A.4b. Matching migration and spawning timing with the recipient temperature regime

Migration and spawning timing must be synchronized with the water temperature regime in the recipient stream to ensure successful fertilization and incubation. This should also result in favourable emergence timing each spring to allow for optimal fry fitness and seaward migration timing (Royal 1953; Sheridan 1962; Godin 1981; Miller and Brannon 1981). Consideration of temperature regimes in the donor and recipient streams is particularly important in situations where at least some natural propagation is desired.

Killick (1955) observed that the adult migration timing of salmon is an inherited, stock-specific trait which reflects the genetic adaption of each race to the distance of the spawning grounds to the sea and to the climatic conditions of the spawning area. Therefore, it would be biologically unacceptable, for example, to transplant an early spawning run into an environment timed for later spawners. Inappropriate temperature regime in the recipient streams was the major factor which plagued the transplant attempts with pink salmon in the Kola Peninsula, USSR (Appendix 29) and of coho salmon in the New England states (Joyner 1973). The use of ATU-MAWW (ie. accumulated thermal units -maximum alevin wet weight) relationship (Table 3; Rombough 1985) together with receiving system's surface water temperature data corrected to reflect subgravel conditions (Shepherd et al. MS 1986) will allow the calculation of spawner or fry emergence timing required.

A.4c. Matching migration distance and route orientation

Consideration should be given to the length, orientation and complexity of the adult and juvenile migration routes. Even where juveniles are released in coastal regions, Thorpe (1980) recommended that the relative orientation of the donor and receiving systems be considered due to the strong genetic component in salmon homing behavior. Similar stream and lake orientations based on compass direction of water flow, and a relatively short and direct freshwater migration route should facilitate juvenile exit and orientation during outmigration, reduce freshwater predation losses (Hartman et al. 1967) and improve homing accuracy. Ricker (1972) recommended that a donor stock which has to make an extensive upstream journey to the new site, should be selected

Table 3. Mean temperature, initial egg weight, time to maximum alevin wet weight (MAWW), accumulated thermal units (ATU, °C.d) and MAWW for chinook salmon[a].

Mean Temperature (°C)	Initial Egg Wt. (mg)	Time to MAWW (d)	ATU to MAWW	MAWW (mg)
5.0	340	200.5	1000	514
7.3	235	135.9	995	375
7.3	341	136.9	1002	542
7.3	384	142.3	1042	552
7.3	437	143.3	1049	634
10.0	163	84.3	860	245
10.2	235	90.8	926	372
10.0	281	89.8	896	371
10.2	340	95.7	955	458
10.2	341	88.3	901	482
10.2	384	94.5	964	493
10.0	425	98.7	985	567
10.2	437	94.5	964	580
12.5	235	64.8	813	343
12.5	341	58.4	732	408
12.5	384	64.9	814	463
12.5	425	62.2	780	512

[a] Extracted from Rombough (1985).

for that characteristic. When transplanting within the same system, the donor stock should come from an upriver rather than a downriver site. Transplants of over 10 million sockeye eggs from the Cultus and Birkenhead systems to the Shuswap area in the 1920s failed, probably at least partly due to the much longer and more complex freshwater migration route to the Shuswap system compared to the donor streams (Foerster 1946). Numerous chinook transplants within the Columbia River watershed failed when downstream stocks were moved hundreds of kilometers into the upstream reaches (Ricker 1972). In contrast, chinook transplants conducted in the Wind and Willamette Rivers, located in the lower Columbia basin, were successful when upstream Columbia River chinook were used as donor fish (Appendices 8 and 9).

Especially in sockeye transplants, donor and receiving systems should be matched as to orientation of the nursery lake and its exit, to the length and orientation of the freshwater migration route, and to the location of spawning area relative to the nursery lake, in order to increase success of smolt outmigration and adult homing. Compared to other salmon species, migration behavior of newly emerged sockeye fry and outmigrating smolts appears to have a more complicated inherent orientation mechanism with a strong genetic component (Groot 1965; Brannon 1967; Hartman et al. 1967; Ricker 1972; Williams and Brannon MS 1972; Wash. Env. Foundation 1983). For example, a sockeye race may have evolved a genetic trait for either upstream (against current) or downstream (with current) fry migration behavior, depending on the location of the nursery lake. Such inherent response to current allows both the inlet-origin and outlet-origin fry to enter the same nursery lake (Brannon 1967; Raleigh 1967). Failure to match migration distance and route orientation in sockeye transplants may result in juveniles experiencing delay or failure in both fry entrance into and smolt exit from the nursery lake (Williams and Brannon MS 1972; Williams MS 1985). Kemmerich (MS 1945) cited several examples of sockeye outplants in Puget Sound where fry released below the nursery lake failed to locate the lake. This failure is true especially if the recipient lake has little or no current or if the current is not consistently oriented downstream (Durkin et al. 1971; Williams and Brannon MS 1972).

The requirement to match the orientation of the freshwater migration route in the donor and receiving systems may be less critical for geographically close transplants as indicated, for example, by chinook transplants from Red Lake to Frazer Lake, Alaska (Appendix 6), and from Big Qualicum River to Capilano River (Appendix 2).

Walker and Lister (1971) suggested that the success of pink salmon transplants may be related to the direction of entry from the sea. Similarly, O'Connell et al. (1983) observed that in transplants of Atlantic salmon in Newfoundland from Adies Stream on the west coast to Upper Exploits River on the east coast (Fig. 5), difference in orientation of the donor and recipient streams may have contributed to the relatively poor initial returns. Poorer homing may have occurred using the Adies donor stock, compared to better homing observed for the later upriver transplants using the lower Exploits River donor stock; the latter fish were the progeny of earlier transplants of Adies fish (Appendix 31). Note however, that the superior homing of the lower Exploits River donor stocks also could be due to local adaptation of that stock.

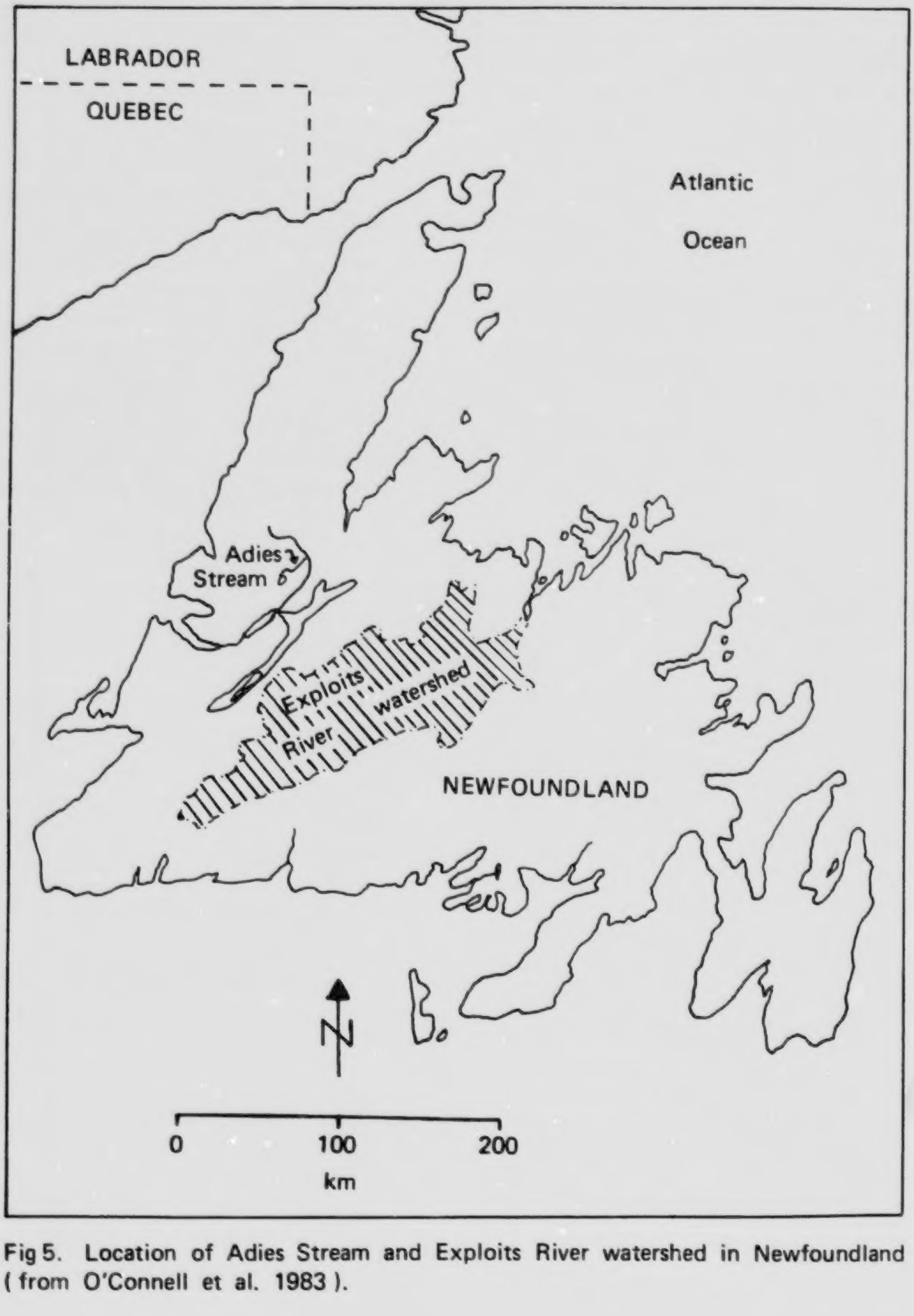
LABRADOR
QUEBEC
Atlantic
Ocean
Adies
Stream
Exploits
River
watershed
NEWFOUNDLAND
N
0
100
200
km

Fig 5. Location of Adies Stream and Exploits River watershed in Newfoundland (from O'Connell et al. 1983).

A.4d. Matching marine conditions

The least known survival component of transplanted salmon occurs during the ocean phase. Small populations not adapted to the peculiarities of the regional temperature and current systems can be easily lost in the enormous marine environment. Therefore in colonization programs, particularly involving distant transplants such as from northern to southern hemisphere or from western to eastern continent, attention must be paid to the marine conditions off the receiving site (Ricker 1954). The matching of donor and recipient sea surface temperature and current patterns should help ensure normal behavior, active feeding and appropriate timing and homing of that species (Harache 1979). Estuarine fertility, intensity of predation, and turbidity as it affects productivity and predation should be also considered as factors effecting marine survival (Koenings and Burkett MS 1985).

Coho transplants in the 1960s and 1970s from Washington and Oregon to Rhode Island and Connecticut (Fig. 6) failed, probably largely due to a warm temperature front (about 16°C) standing in the coastal area until late fall, which prevented the southern migration of adults to their new home streams (Joyner 1973; Harache 1979). In contrast, the same donor stocks of coho transplanted in the more northern state of New Hampshire were much more successful, probably due to the cooler offshore water temperatures in that region (Appendix 24). Joyner (1973) suggested that the Connecticut and Rhode Island transplants would have been more successful using later-timing donor stocks returning during a later, cooler period.

In New Zealand, introduced chinook are widespread on the South Island but not on the North Island, possibly because warm sea water temperatures towards the equator limit the northward distribution of chinook (Anon. 1983). In Chile, chinook colonization programs are concentrated in the southernmost streams which are at the same latitude and therefore have a similar temperature regime as the successfully colonized New Zealand streams. Colonization attempts with chinook, coho and chum conducted north of Puerto Montt prior to 1972, generally failed to produce returns, possibly due to unfavourable ocean current patterns. It appears that the west wind drift that strikes the Chilean coast at about 42°S latitude between Puerto Montt and Puerto Aysen (Fig. 7), becomes divided in this region into north and south currents whose proportional strength depends on the season (FFI 1983; M. Winsby, pers. comm.). The northern current flows linearly and is known as the Humbolt Current. The southern current is gyre-like and flows in a turbulent, slow, non-linear pattern towards Cape Horn; this current is rich in plankton and other salmon feed. According to the theory, salmon entering the sea north of Puerto Montt are transported north by the linear Humbolt Current. The combined effects of current strength and pattern, warmer water temperatures and other factors apparently affect the fish in such a way that the returns are poor. By comparison, salmon entering the sea south of Puerto Montt graze in the cool rich feeding grounds where a system of eddies allows for a more local distribution and a better homing and survival (FFI 1983). However, southern releases may migrate too far south and become lost in the circumpolar current (M. Winsby, pers. comm.). He cited an example where chinook juveniles released at 43°S latitude produced a good return of 1-2%. By comparison, a release of about 12 million chum fry of Japanese origin at 46°S latitude produced a negligible return of $<0.001\%$. Chum, as a species, migrate further out to sea than chinook, and this feature, combined with their more southerly release possibly resulted in an excessive transport into the circumpolar currents.

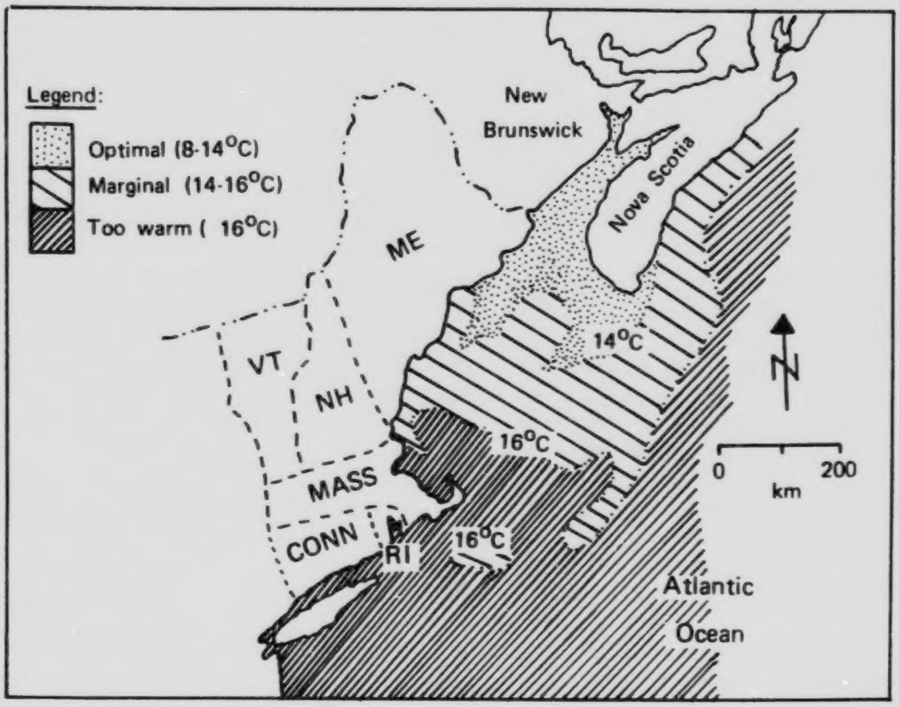
Legend:
Optimal (8-14°C)
Marginal (14-16°C)
Too warm (16°C)
New Brunswick
Nova Scotia
ME
VT
NH
MASS
CONN
RI
14°C
16°C
16°C
0
200
km
Atlantic Ocean

Fig. 6. New England coastline showing September sea-surface temperatures in the Gulf of Maine suitable for Pacific salmon (from Joyner 1973).

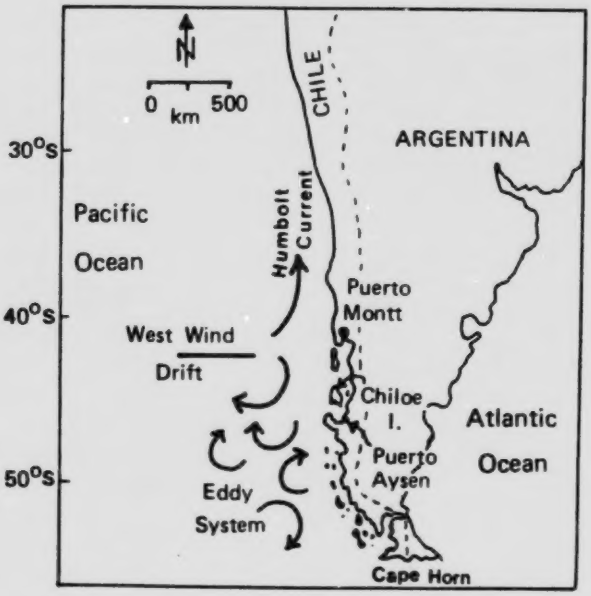
0
500
km
CHILE
ARGENTINA
30°S
40°S
50°S
Pacific Ocean
Humbolt Current
West Wind Drift
Eddy System
Puerto Montt
Chiloe I.
Puerto Aysen
Cape Horn
Atlantic Ocean

Fig. 7. Southern Chile; arrows indicate direction of current with 'current break' occurring at about 42°S latitude (from FFI 1983).

The above list of biological and environmental characteristics to be considered in transplant programs is similar to the one developed independently by the South Coast Geographic Working Group in their Transplant Policy for British Columbia (Table 4; Anon MS 1982). Although their guidelines were developed for selecting coho donor stocks, some of these guidelines may apply to other salmon species.

A.5 DISEASE PROFILES

The use of pathogen-free or disease-resistant donor stocks is necessary to prevent the spread and introduction of disease agents, and to increase the overall transplant survival. Salmon are affected by a variety of diseases, including viruses, bacterial infections, gill diseases, and internal and external parasites. Although many of the infectious diseases are widespread, some such as Myxosoma cerebralis (whirling disease) and viruses of haemorrhagic septicemia (VHS), infectious pancreatic necrosis (IPN) and infectious haematopoietic necrosis (IHN) occur in certain areas only (Transplant Committee MS 1977).

Some fish can act as carriers of disease agents, which cannot be detected in these specimens (Transplant Committee MS 1977). Bullock et al. (1976) observed that several destructive diseases causing large financial losses have been transmitted via contaminated fish and possibly also by surface-disinfected eggs.

Resistance of donor stocks to pathogens in the receiving waters must also be considered. For example, transplants of summer steelhead in the early 1970s to the Willamette River in the Columbia basin failed largely due to the susceptibility of the donor stock to Ceratomyxa shasta (D. Buchanan, pers. comm.). Similarly, efforts to enhance the production of introduced sockeye in Lake Washington have failed repeatedly due to severe IHN outbreaks in the hatcheries (J. Ames, pers. comm.). Juvenile sockeye appear to be more vulnerable to diseases (IPSFC 1970) than coho (Anon. 1975) and chinook (D. Ortman, pers. comm.), both of which can be readily reared in hatcheries to smolt size. In contrast, sockeye production in hatcheries has met with only limited success in Alaska and the Pacific Coast, largely due to losses from IHN (SSRAA 1983a, 1984). Although this pathogen presently has no known cure, researchers in the United States have recently developed sockeye rearing techniques which reduce the IHN risk; the techniques include the development of a virus-free broodstock and release of IHN-free juveniles (SSRAA 1983b).

To guard against the transmission of diseases between areas, the Interagency Committee on Transplants and Introductions of Fish and Aquatic Invertebrates in B.C. requires that the transplant proposal include the available disease history of the proposed donor stocks and of stocks in the receiving waters, and any precautions to be taken to avoid introduction and spread of diseases (Transplant Committee MS 1977). At present, the Transplant Committee has no clearcut, definitive guidelines for establishing a disease profile for a given stock and each case is considered on its own merit (D. Kieser, pers. comm.). However, disease zoning maps currently being developed for British Columbia by the DFO Diagnostic Service should facilitate the evaluation of stock disease profiles. The Committee has recommended the following procedures for transplant programs in British Columbia:

Table 4. Guidelines for selecting coho donor stocks---transplant policy for British Columbia (South Coast Geographic Working Group)[a].

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a. Do not mix coastal and interior stocks. For example, biochemical, meristic and other evidence show differences between coho stocks spawning upstream of the Fraser River Canyon and those spawning in the lower Fraser and in coastal streams of mainland and Vancouver Island (Taylor and McPhail 1985).

b. Do not mix coho stocks from north and south of Campbell River on Vancouver Island. Coho from these two areas (Fig. 8) are not panmictic (ie, are not genetically similar) as indicated by hydrographic and other evidence.

c. Do not mix stocks from large stable rivers with stocks from small unstable rivers. Salmon life histories, based partly on genetic characteristics, are likely to differ between the two types of rivers.

d. Match life histories. Transplants are most likely to succeed between stocks with similar migration and spawning timing, adult body sizes, length of juvenile stream residency, etc.

e. Match habitat characteristics. Transplants are more likely to succeed between streams with similar habitat characteristics such as flow and temperature regimes, pH values, stream gradient and substrate type.

f. Prefer geographic proximity. Given two potential donor stocks with equal ratings according to life history and habitat profiles, select the one geographically closest to the recipient stream.

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[a] Extracted from Anon (MS 1982).

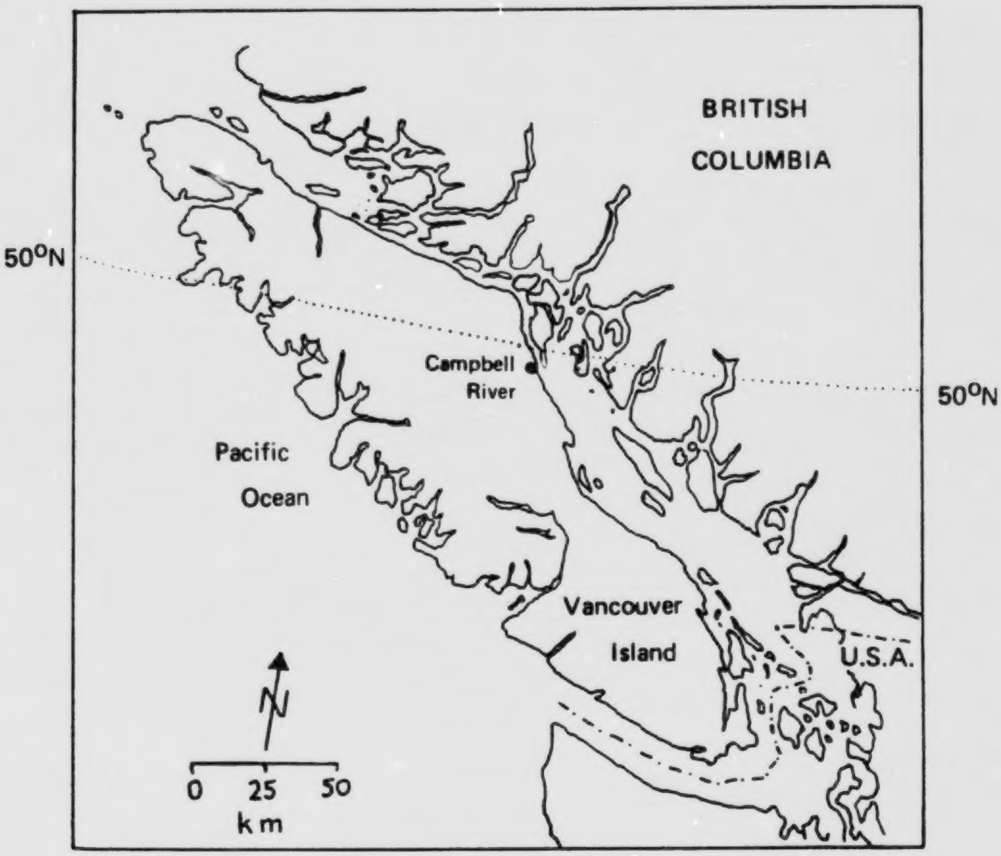
BRITISH
COLUMBIA
50°N
50°N
Campbell
River
Pacific
Ocean
Vancouver
Island
U.S.A.
N
0
25
50
km

Fig. 8. Location of Campbell River on Vancouver Island, B.C.

a. Transfer fish or eggs only within a tributary or adjacent tributaries of a watershed where straying of fish and mixing of waters over the years probably have resulted in similar disease situations.

b. Transfer surface-disinfected eggs from health-checked parents, since egg transplants pose a reduced threat of disease transfer compared to the introduction of older fish stages.

c. When outplanting juveniles, transfer younger fish stages since they have a reduced chance of contacting and harbouring disease agents from their native streams.

d. Culture transplanted fish in groundwater under isolated conditions from other stocks.

e. Avoid introduction of undesirable aquatic plants and animals which may act as vectors of disease, by using groundwater for transport and by disinfecting water and fish.

Recently, the DFO Regional Planning Group has prepared under contract "disease maps" that may be of use in determining donor stock suitability.

A.6. FISH QUALITY

The adult progeny from transplants should retain their quality until harvest time in order to maximize the economic value in a terminal fishery. Holmes (MS 1982) observed that upriver Bella Coola stocks retained their quality longer than downriver stocks from the same system. Thus, choice of an upriver population as a donor stock could have additional benefits beyond improved homing (see section A.4c.)

A.7. OCEAN DISTRIBUTION AND MIGRATION TIMING

Since the ocean distribution and migration timing of salmon stocks is at least partially genetically controlled (Ricker 1972; Saunders 1981; Wash. Env. Foundation 1983), donor stocks may be chosen and further selected to produce a fishery time and space that will best serve the demands of the user groups and reduce conflicts with mixed-stock fisheries (Hopley 1978; Howell et al. 1985b). A potential donor stock with a preferred marine distribution and a wide timing range could be used to develop an early, mid- or late spawning run. For example, at the Capilano River and Robertson Creek hatcheries, coho runs were separated into early, mid- and late run components and these were crossed in different combinations such as early x early, early x late and late x late (T. Perry, pers. comm.). The timing of returning progeny for each group was similar to that of the parental broodstock, with some overlap between groups, suggesting an inherited tendency in migration timing. The above experiments showed that selective removal of a broodstock from a given population may be used as a tool for developing a desired run timing in the returning progeny.

In the lower Columbia River, a late fall net fishery for coho was developed by enhancing the later run segment of the Cowlitz River donor stock (Hopley 1978). In chinook transplants to the Willamette River, the early spawning Tule stock and the late spawning Cowlitz stock were selected to develop a commercial fishery and a freshwater sport fishery respectively

(Appendix 9). In Puget Sound, Dungeness River chinook are considered to be especially well suited for enhancing that region's sport fishery due to their local marine distribution (Geist 1978). The selective development of broodstock has been demonstrated to be an effective management tool for transplants in Washington and Oregon (Howell et al. 1985b).

The above list of guidelines concerning donor stock characteristics is similar to the one developed independently by the Idaho Department of Fish and Game (Table 5; Howell et al. 1985b).

B. SELECTION OF RECEIVING SITES

In establishing successful transplants, a number of receiving site characteristics should be considered. These requirements are discussed in the following 11 sections.

B.1. AVAILABILITY OF DONOR STOCKS

See sections A.1 to A.7 above for donor stock requirements.

B.2. ABSENCE OF WILD STOCKS

The receiving watershed preferably should have no wild stocks for several reasons:

a. To reduce the potential for genetic pollution. Genetic pollution of wild stocks through straying of transplanted fish may be expected if streams with significant wild stocks exist near the recipient system. Interbreeding between hatchery and wild stocks may result in a decline in fitness of the wild stocks (Lister et al. 1981; Reisenbichler MS 1986). Studies with brook trout, Atlantic salmon and steelhead indicate that considerable genetic differences which may affect growth and survival exist between hatchery and wild fish, with wild fish surviving better than hatchery fish in natural streams (Reisebichler and McIntyre 1977). Considerable interbreeding of hatchery and wild chinook probably exists in the Columbia River basin due to extensive introduction of hatchery stocks in that region (Howell et al. 1985a). Also in New Zealand where an estimated natural straying of about 10% is observed among returning chinook, considerable genetic mix may be expected between hatchery and wild stocks in areas with hatchery releases (Anon. 1983).

   It should be noted, however, that at present no hard evidence exists for reduced fitness of hatchery fish compared to wild fish, except where intensive fish farming involving broodstock selection is conducted. Therefore, the judicious use of local wild stocks for hatchery boodstock may well serve to improve the fitness of hatchery stock without significant long-term negative effects on the local, wild populations.

b. To reduce predation and competition in freshwater and early marine residency (Reisenbichler and McIntyre 1977; Wash. Env. Foundation 1983).

c. To reduce the risk of disease transmission to wild stocks.

Table 5. Existing stock transfer guidelines for Idaho (Idaho Department of Fish and Game)[a,b].

Donor stocks will be of the same race or strain (eg. spring chinook versus summer chinook).

Donor stocks should be closely related geographically.

Upstream and downstream migration timings should be matched as closely as possible.

Spawning timing should be matched as closely as possible.

Genetic makeup, when known, should be closely matched.

For geographically distant donor stocks, as with sockeye in Idaho's program where donor stock comes from central British Columbia, more than 1000 km from receiving site, utilize a stock with a lengthy freshwater migration.

Differences in migration timing of donor stocks may be sought to enhance fishing opportunity.

Differences in size of mature fish in the fishery (a function of the number of years at sea) may be sought in a donor stock when it would enhance a fishery.

Survival rates, usually expressed as smolt-to-adult, but with particular emphasis on headwaters-to-ocean and in-ocean survival rates, should be compared among potential donor stocks.

Disease histories of donor stocks should be equal to, or better than, the original stocks.

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[a] Extracted from Howell et al. (1985b).

[b] Characteristics are not necessarily in order of priority.

d. To avoid overharvesting of wild stocks in "mixed stock" terminal fisheries.

B.3. ACCESS TO RELEASE SITES

See section A.2.

B.4. SPAWNING AND REARING CAPABILITIES

At the recipient site where at least partial natural propagation of the transplanted fish is desired, major habitat requirements common to all Pacific salmon must be met. These include physical characteristics such as stream gradient, current velocity, substrate type and composition, water depth, presence of stream cover and channel stability (Wash Env. Foundation 1983), as well as water quality characteristics. Sigma Environmental Consultants (MS 1983) summarized the recommended water quality criteria for the intensive culture of salmon in fresh water. It should be noted that habitat requirements can be species-and stock-specific. For example, the two discrete chinook stocks in Kenai River, Alaska, have different freshwater requirements (Burger et al. 1985). In addition, requirements can differ for the hatchery and natural environments; more restrictive habitat criteria generally would be applied to cases where natural runs are to be established, while more demanding water quality criteria would be set for the high-density hatchery situation.

The authors recommend that biophysical stream surveys (De Leeuw MS 1981) and lake surveys (Hyatt and Stockner 1985) be undertaken to estimate natural spawning and rearing capabilities where such activities are desired. For example, K. Hyatt (pers. comm.) observed that lake area and total phosphorus levels are among the key indicators of a lake's carrying capacity for sockeye. The stream and lake surveys should also include predator/competitor considerations (see section B.9).

B.5. FOOD SUPPLIES

An adequate food supply in the release system is one of the major requirements for the successful survival of juveniles and is especially important for establishing self-sustaining runs of chinook, sockeye and coho, all of which undergo a freshwater rearing phase. Koenings and Burkett (MS 1985) observed that the receiving sockeye nursery lake should show an appropriate seasonal timing of preferred forage items for fry, and sufficient density and body size of forage species to allow for efficient fry growth rates. In British Columbia, the production of sockeye has been increased significantly in recent years as a result of lake fertilization programs (Hyatt and Steer MS 1985) and there is considerable evidence that smolt size is directly related to zooplankton abundance in a lake (Hyatt and Stockner 1985).

Among chinook introductions, the successful landlocked transplant into Lake Sakakawea, North Dakota, was partly attributed to the abundance of rainbow smelt in the reservoir, which provided a high quality forage base for the piscivorous chinook (Appendix 11). Similarly, landlocked chinook planted in Lake Coeur d' Alene, Idaho, thrived on the abundant kokanee (Appendix 10). In the Great Lakes, transplanted chinook and coho did much better in Lake Michigan which has a strong forage base consisting primarily of alewives, compared to other Great Lakes which have a poorer forage base (Appendices 5 and 22).

Based on the above, it is recommended that biophysical surveys of candidate transplant systems should include examination of potential forage base over the projected rearing period.

B.6. WHY IS THE SYSTEM BARREN?

Withler (1982) noted that introductions of anadromous Pacific salmon within their natural range generally met with failure, except where an obvious physical barrier had prevented natural colonization. Examples of successful salmon transplants where a barrier falls was a major reason for the absence of natural runs include chinook and sockeye transplants in Frazer Lake (Appendices 6 and 16), sockeye transplants in Great Central Lake (Appendix 15) and chinook transplants in Wind River (Appendix 8) and Willamette River (Appendix 9). Withler (1982) concluded that a transplant is most likely to succeed in situations where an obvious physical obstruction blocks upstream access to the potential spawning and rearing areas. A major exception was a sockeye transplant into the Lake Washington system which had no physical barrier to upstream migrants but where Cedar River, the major potential sockeye spawning stream,bypassed the lake prior to its diversion into that lake (Appendix 17). In addition, pollution-related fertilization of Lake Washington may have benefited juvenile survival.

Dept. Fish. Canada (MS 1966) cautioned that there must be reasons why a stream is barren of salmon; in the absence of a physical barrier, a complex series of biological, physical and chemical factors may be present that will confound transplant attempts.

We therefore recommend that if the preliminary survey reveals no basic cause for the barren state of the system, no major transplant should be undertaken. Instead, a bioassay study should be considered to indentify the problem.

B.7. WATER SOURCE FOR IMPRINTING

Springs or small tributaries in the vicinity of a fish release site may strongly influence homing behavior and therefore may be important in the selection of release locations (Jensen and Duncan 1971).

B.8. FRESHWATER MIGRATION ROUTE

A short and direct freshwater route is preferred. See section A.4c with regard to matching migration distance and route orientation.

B.9. PREDATION AND COMPETITION

Reducing competition and predation during the freshwater life stage is important when transplanting chinook, sockeye and coho due to their prolonged rearing in freshwater. Numerous studies, such as in Shuswap Lake (IPSFC 1976) and in lakes in Alaska (Hartman et al. 1967), indicate that predation can account for substantial losses of young sockeye during lake residence and emigration. The highly successful chinook and coho transplants in Lake Michigan are partly attributed to control of sea lampreys and the absence of competition by other large piscivorous species (Appendices 5 and 22). The transplant of kokanee in Lake Koocanusa, Montana, probably succeeded partly due to the absence of competition by other planktivorous fish (Appendix 20).

We recommend that biophysical surveys of streams and lakes being considered as transplant candidates, should include studies of distribution and abundance of potential predators and competitors.

B.10. MARINE ENVIRONMENT

Evaluation of the nearshore marine environment at the receiving site should include the availability of sheltered areas for early ocean rearing (Anon. 1983) and biophysical characteristics such as dissolved oxygen, salinity, transparency, chlorophyll a content and zooplankton composition (Hatfield Consultants Ltd. MS 1985).

B.11. TERMINAL FISHING SITE

If a transplant is to be successful for large-scale salmon production, there should be a suitable terminal fishing area near the system. The terminal fishery site should be isolated from the migratory paths of wild stocks in order to allow for discrete harvesting of introduced fish without exploitation of wild stocks. It should also be selected for physical features such as adequate fishing area and safe fishing conditions (for example, adequate operating depth, low current strength and protection from storms). Another consideration is the potential loss in fish quality which is often encountered in terminal fisheries (Snyder MS 1983). An example of a suitable terminal fishing area is Neets Bay in Alaska which offers a large deepwater bay that can accommodate several types of commercial harvesting techniques and supports no significant native stocks (FFI 1984b).

C. SELECTION OF FISH CULTURE, RELEASE, AND FISHERY STRATEGIES

The following 13 recommendations are made regarding fish culture, release, and fishery strategies to increase the survival of transplanted fish and their initial progeny.

C.1. SIZE AND DURATION OF OUTPLANTS

Large-scale salmon introductions combined with a prolonged planting period are two factors critical in generating a viable run in a new system (Ricker 1954; IPSFC 1960; Ricker 1972; Lear 1975; Harache 1979). Large plantings must be conducted, at least initially, to provide increased genetic diversity and an adequate pool from which the selection process can weed out genes maladjusted to the new environment (Ricker 1954; Brannon MS 1970). The benefits of massive outplants also include reduced predation and greater adult returns despite possible heavy fishery exploitation (Ricker 1972). Blackett (1979) felt that the technology was presently available to produce large outplantings of sockeye fry and eggs to overcome the high freshwater mortality. He predicted that with the new technology, substantial adult returns may be gained in the first 5-or 6-yr cycle rather than the 20-to 25-yr period observed in the Frazer Lake project. In addition to large outplantings, a prolonged transplant period is necessary since the transplanted stock may be genetically weak for the first few generations while the poorly adapted genes are weeded out.

Massive and prolonged outplants have characterized several successful transplants. In Frazer Lake, Alaska, approximately 8 million sockeye eggs, 3 million fry and 30,000 adults were outplanted during a 10-yr period (Appendix 16). This ambitious program continued until natural returns and production were sufficient to maintain a viable run. Other examples include chinook transplants in Great Lakes where 6 million juveniles were released between 1967 and 1970 (Appendix 5); chinook transplants in Wind River where about 500 adults and 1 million juveniles were transplanted annually over a 10-yr period (Appendix 8); chinook transplants in Willamette River where 5-12 million reared juveniles were transplanted annually since 1970 (Appendix 9); sockeye transplants in Great Central Lake where approximately 20 million eggs were transplanted during a 10-yr period between 1921 and 1932 (Appendix 15); and pink transplants in the Kola Peninsula, USSR, where a total of about 200 million juveniles were released during the 1960s and 1970s (Appendix 29).

In contrast to above, the majority of unsuccessful transplants are characterized by very brief attempts usually lasting 1-3 yr and involving less than 500,000 eggs or juveniles each year. Where returns were observed, the numbers were often insufficient to establish a self-sustaining run and the "infant" population died off. Examples of such failed transplants due to limited effort include sockeye transfers from Cultus Lake to Eagle River in British Columbia, coho transfers from Lewis River, Washington, to Sacramento River, California, and pink transfers from Skagit River, Washington, to rivers in Maine (Ricker 1972). Low adult returns following sockeye transplants to various rivers in the Fraser River watershed, including Upper Adams, Barriere, Portage Creek and Middle Shuswap, could also be partly attributed to low levels of egg transplants (approximately 200,000-300,000 eggs/yr) combined with intermittent outplants (IPSFC 1960; J. Woodey, pers. comm.). In sockeye transplants to Lake Washington, significant returns were observed only after some 30 yr following the initial colonization, probably partly due to low fry outplants of less than 100,000/yr (Appendix 17).

Walker and Lister (1971) suggested that the optimum magnitude and duration of a transplant is specific to a particular case. The recommended levels in literature range from 1 million to 25 million eggs or fry each year and at least one complete cycle of 4 yr for chinook and sockeye to 10 yr or more until a viable population becomes established. Thus, IPSFC (1960) recommended that for economically viable sockeye returns, transplants should range between 1 and 3 million eggs each year. Ricker (1954) recommended annual transplants of 15-20 million eggs for pink colonizations. Lear (1975) suggested that for long distance transplants of pink salmon from British Columbia to Newfoundland, annual plantings of 10-25 million eggs should be made to allow for the natural selection process to weed out the unfavourable individuals and also to recover from years of low marine survival due to adverse environmental conditions. In transplanting chinook, Withler (1982) suggested that the effort should be sustained for at least one complete cycle or a minimum of 4 yr, in order to increase chances of establishing a successful run.

Based on the above, we recommend a minimum of 1 million eggs for annual transplants over a period of 10 yr.

C.2. SIZE OF GENE POOL

Wild salmon stocks have evolved over numerous generations through the process of natural selection to become specifically adapted to their environment (Dept. Fish. Canada MS 1966). Many stock traits of salmon are totally or partially genetically controlled. These traits include marine distribution, homing ability, freshwater and marine migration patterns, migration and spawning timing, spawning and rearing habitat preference, growth rate, age at smoltification, age and size at sexual maturity, and disease resistance (Saunders 1981; Ricker 1972; Wash. Env. Foundation 1983). It should be noted, however, that despite specific adaptations, salmon are obviously resilient in that they have strayed extensively in the post-glacial period and succeeded in occupying numerous streams. Natural straying of salmon continues to this day.

Because of the multitude of genetic factors involved, perfect matching of donor and recipient characteristics in a transplant is impossible. The introduction of a genetically diverse broodstock should speed up the process of natural selection and improve fitness of the transplanted stock allowing it to cope with varying freshwater and marine conditions such as fluctuation in temperature, in food and in predator abundance (Lear 1975; Geist 1978; Snyder MS 1983). A large gene pool may be particularly important in transplants of sockeye which seem to be one of the least successful colonizers among salmon species (B. Riddell and K. Groot, pers. comm.). These scientists believe that unlike coho and Atlantic salmon which seem to imprint readily to the new release site, sockeye with their apparently more rigid homing behavior and strong inherent orientation mechanism, are a more conservative, less flexible species.

Brannon (MS 1970) suggested that previous sockeye transplants generally failed to "take" due to the limited gene pool available using a single donor stock and small-scale introductions. This approach probably led to low adaptive flexibility and slow natural selection. Brannon also cautioned that even with careful matching of the donor and recipient environments, only a few deviants from a transplanted stock may survive in the new environment, given the apparent strong genetic control of certain characteristics such as migratory behavior of sockeye fry. He postulated that by transplanting large numbers of fish and thereby increasing genetic diversity, the success of a transplant could be greatly increased.

In order to further increase genetic diversity and thereby accelerate genetic changes, Brannon (MS 1970) also suggested the use of several donor stocks and their hybrids in a transplant. He observed that population studies have shown that racial characteristics can be partially or completely broken down by cross-mating stocks. The hybrid has three features: a disrupted genetic homeostasis (a mechanism that resists genetic change), reduced race-specific traits, and greatly increased genetic variability. These features should allow new gene combinations to arise, providing a much wider base for natural selection pressures. Brannon still cautioned that the choice of donor stocks remains of prime importance and that races selected for cross-mating should be geographically close and well-matched to the new environment. The reason is that hybrids produced from stocks selected for certain traits will still show these characteristics but in different intensities.

Successful transplants which have utilized genetically diverse donor populations include chinook and coho introductions in Great Lakes (Appendices 5 and 22) and chinook transplants in Wind and Willamette Rivers (Appendices 8 and 9). In coho transplants in Alaska, up to seven non-indigenous donor stocks have been used in developing broodstock that will support a terminal fishery (Heard 1978). In the New Hampshire coho transplants, several donor stocks were used, but only one showed superior survival (Stolte 1974). This reinforces the need to use a variety of donor stocks since some will do better than others. A few single stock transplants have also resulted in successful self-sustaining runs, but these efforts were characterized by prolonged colonization efforts or large outplantings. Examples of the latter include chinook transplants in New Zealand (Appendix 12) and sockeye transplants in Frazer Lake, Alaska (Appendix 16), and in Lake Washington (Appendix 17).

From the above it is concluded that two separate approaches may serve to increase genetic variability in a transplant: 1) the use of large-scale transplants and 2) the use of several donor stocks and their hybrids. In a large transplant, inbreeding is reduced, genetic diversity is increased, and the survival of desired types is enhanced (Brannon MS 1970; Moller 1970; Wash. Env. Foundation 1983). The use of a variety of pure stocks and their hybrids should speed up the selection process and result in a genetically pliable and resilient broodstock (Brannon MS 1970; Lear 1975). Riddell (pers. comm.) suggested that the pure and hybrid stocks should be differentially tagged to enable the selection of the most successful broodstock. Appropriate hatchery breeding and rearing practices should also be adapted, such as maintaining 50:50 spawner sex ratios during egg-takes in order to encourage a wide gene pool.

Based on this review, we recommend that a minimum of three suitably matched donor stocks and their hybrids, crossed both ways, be used in a transplant to give a total of nine donor groups. This approach is particularly recommended for sockeye transplants, for cases where at least partial natural propagation is desired, and where well-matched donor stocks are not available. The resulting genetically-rich broodstock should lead to accelerated natural selection and ensure long-term productivity and viability of the transplant.

C.3. LIFE STAGES TRANSPLANTED

Colonization studies on salmon have shown that the survival of transplanted eggs, fry and adults can be highly variable (Blackett 1979). Therefore, using a combination of egg to adult stages in transplants may increase the chance of success. The success of sockeye transplants in Frazer Lake may be partly attributed to a multiple planting approach, with fry plants probably yielding best results (Appendix 16). The successful sockeye transplants in Lake Washington utilized a variety of juvenile stages ranging from 0.2 g fry to 6.9 g yearlings (Appendix 17).

C.4. TRANSPLANT METHODS

The development of transfer and planting methods will depend on such factors as the accessibility of the donor and receiving sites, life stages transplanted, and the intensity of artificial propagation. Blackett (1979) detailed the techniques used for planting sockeye eggs and fry, and for transplanting adults into Frazer Lake, Alaska. The egg-planting technique utilized a method where advanced eggs were outplanted into natural substrate thereby shortening the period of egg concentration in the gravel before alevin dispersal. Fry planting involved airlifting and acclimation of fry to lake water temperature prior to release. Adults were also airlifted into the lake, and the lake's outlet was barred with a weir to retain the adults in the system.

C.5. JUVENILE RELEASE SIZE

Numerous studies have shown that marine survival is related to the size of outmigrating juveniles, and that this is partly due to the lower vulnerability to predation by larger fish (Foerster 1954; Ricker 1962; Carlin 1968; Wash. Env. Foundation 1983; Hyatt and Stockner 1985; Koenings and Burkett MS 1985). Under natural conditions, over 90% of the fry may be eaten by predators, before they enter the estuaries (pink and chum) or lakes (sockeye) (Wash. Env. Foundation 1983).

Vernon (1982) noted that predation is a significant cause of mortality during the freshwater life of sockeye juveniles. Bams (1967) showed that larger sockeye fry exhibit a better swimming performance and avoid predators more successfully than smaller fry. Williams (MS 1985) found that short-term rearing of sockeye fry for 6-8 wk can double the natural survival to the smolt stage, largely due to reduced vulnerability to predation. Hyatt and Stockner (1985) observed that a twofold or greater mean increase in marine survival may be expected for sockeye from fertilized British Columbia coastal lakes, due to greater smolt size. Studies in Alaska showed that ocean survival of sockeye increased from 4% to 35% as the smolt release size increased from 2.2 to 8.0 g (Koenings and Burkett MS 1985). These authors found that further increases in size to 30 g resulted in little additional improvement in estimated ocean survival. Ricker (1962) likewise observed the correlation between sockeye smolt size and ocean survival and noted that this correlation became less apparent beyond a smolt size of about 8 g.

Survival of chinook is also related to size at release (Reisenbichler et al. 1982). Ricker (1972) observed that transplant releases of chinook juveniles less than 5 g in size may partly explain many past chinook colonization failures. According to recent experiments in New Zealand, release weight may be the single most important factor influencing chinook returns (Unwin MS 1985). In those studies, the New Zealand scientists observed that the release weight of chinook correlated directly with percent return irrespective of release date, and each 10 g weight increment within a weight range of 10-70 g, translated into a 1% increase in adult return. A recent July release of 65 g chinook juveniles from a New Zealand hatchery has resulted in a 3-yr-old return rate of 5.5% (Todd 1985); the expected survival including the 4-yr-olds is 6.5-7% (G. Glova, pers. comm.). In Alaska, releases of 30 g yearling chinook smolts in May and June generally result in a 6% survival with no reported problem regarding the proportion of jacks (K. Johnson, pers. comm.). Recent experiments in British Columbia hatcheries with coastal chinook demonstrated that as smolt size increased so did marine survival with a shift in adult age composition to younger ages (Bilton 1984). Despite the age shift, the absolute numbers of fish returning and the harvestable biomass were much greater than at lower smolt size, resulting in overall benefits to production.

Survival of coho is also related to size at release (Mahnken et al. 1982; Bilton et al. 1982, 1984). In estuarine pen culture of coho in Alaska, releases of 8-16 g yearling smolts have resulted in adult returns of around 9% (Heard 1978). At other hatcheries in Alaska, yearling coho are released at about 25 g in June giving an 11% return rate (K. Johnson, pers.comm.). Bilton et al. (1982, 1984) observed that both time and size at release have a significant effect on coho returns. Maximum returns were obtained with releases of 15-25 g smolts in June. Maximum returns of jacks occurred from early releases of large juveniles (>20 g in April). It should be noted that increased proportion of jacks in the returning transplant progeny need not be a problem, at least in the initial stages of the program, since jacks can provide viable milt for hybrid crosses with donor females.

Heard (1978) observed that the appropriate stocking size may depend on the presence and size of predators in the receiving body of water. For example, in coho stocking programs in Alaska, coho fry are normally planted into barrier lakes at 0.3-0.4 g. However, barrier lakes with Dolly Varden predators are planted with 1 g fry. In addition, the coho fry are planted in mid-July in order to coincide with the mid-summer plankton bloom. The resultant rapid growth of juveniles further reduces predation by Dolly Varden.

Neave (1965) reviewed the transplants of pink salmon and noted that size at release and the abundance of predators along migratory routes of juveniles may be important factors affecting transplant survival. He cited the pink transplants in Kola Peninsula, USSR, where fry migrating at 0.2 g were preyed on heavily by marine fish in bays of the Barents Sea, while fry migrating at 0.35 g left the bays quickly and thereby suffered less predation. Lear (1975) reviewed the unsuccessful transplant attempts of pink salmon in Newfoundland and suggested that the release of larger fry should enhance the probability of transplant success.

Size at release also directly affects return rates of Atlantic salmon (Larsson 1977) and steelhead (Wagner et al. 1963). For example, in transplants of steelhead into the Willamette River in the Columbia basin, larger-sized juveniles are released to increase transplant success (D. Buchanan, pers. comm.). In Japan, older and larger juveniles are routinely released in order to increase marine survival. This approach has resulted in up to a 5% return rate for chum releases (FFI 1977; Unwin MS 1985).

Based on the above, we propose the following general recommendations regarding size of juveniles at release (Table 6): chinook at 12-30 g, coho at 15-25 g and sockeye at around 8 g. Release of healthy and sufficiently large juveniles should give them a competitive edge during the early rearing phase, especially regarding predatory losses, thereby increasing the marine survival.

C.6. JUVENILE RELEASE TIME

The following recommendations can be made regarding release timing of juveniles (see also section C.5):

a. Avoid prolonged natural rearing in fresh water where a high freshwater mortality may be expected (Koenings and Burkett MS 1985).

b. For lake-rearing sockeye, match release timing to the start of the plankton bloom (Shepherd 1984b). Note that the type and size of plankters in the bloom should be those important as food items (Koenings and Burkett MS 1985). In Japan, release timing from hatcheries coincides with peak densities of the most suitable natural forage species in streams and coastal waters into which chum fry are released (FFI 1977).

c. Where a more local marine distribution and increased availability to

Table 6. Recommended smolt release sizes for chinook, coho and sockeye to maximize returns in transplant programs.

Species	Recommended Size	Comments	References
Chinook	12-30 g	- time of release also affects return rates; suggest early to mid-June releases - proportion of 2-yr-olds (jacks) increases at greater smolt size but the benefits in harvestable numbers and biomass remain considerable	Bilton 1984; T. Perry (pers. comm.)
Coho	15-25 g	- both size and time of release significantly affect return rates; suggest June releases with fine tuning of release size and timing for maximum benefit/cost ratios - production of jacks is favoured by early release of large juveniles (eg. 30 g in early May)	DFO Info Memo No. 1, May 1979; Bilton et al. 1982; Bilton et al. 1984
Sockeye	8 g	- larger smolts return as adults at younger age but the increased proportion of 2-yr-olds is not striking; the resultant increase in numbers and biomass of adults remains significant despite some reduction in mean age at return - effects of smolt size on adult age and size composition and on marine survival are modified by smolt abundance and migration timing	Ricker 1962; Hyatt and Stockner 1985; Koenings and Burkett MS 1985

local fishermen are desired, delayed hatchery release of coho might be useful (Mahnken and Joyner 1973). This approach is used successfully for coho in Puget Sound (FFI 1975a).

C.7. ACCLIMATION OF JUVENILES

Fish may be stressed severely by handling procedures involved in collection and transportation (Mazeaud et al. 1977; Strange et al. 1977). Acclimation to the recipient site before release will help dissipate stress from handling, as well as improve homing through imprinting (see section C.10). For example, L. Korn (pers. comm.) recommended building acclimation ponds at chinook release sites in the Willamette River system; presently, the transplanted fry are released directly from trucks into the river. In Iceland, transplanted Atlantic salmon juveniles are held for several weeks in acclimation ponds prior to release in order to improve survival and homing (Isaksson et al. 1978).

Matthews et al. (1986) used a static seawater challenge test to assess stress from collection and transportation procedures on migrating spring chinook smolts in the Columbia River system. It was tentatively suggested that, following trucking or barging, smolts should be held for a day in fresh water prior to their release in the river. For purposes of acclimation only, we recommend a lower holding limit of 30 min when little or no stress on fish is apparent, in order to establish a thermal equilibrium between transport and receiving waters, and a maximum holding limit of 2 d when severe stress from handling during transport is suspected.

C.8. DISPERSAL OF TRANSPLANTED FISH

Transplanted salmon should be dispersed in order to maximize the use of the available natural spawning and rearing areas at the recipient site. Sockeye adults originating from egg transplants in the Upper Adams River returned precisely to the egg planting sites (Ricker 1972). In chinook transplants to Frazer Lake, Alaska, adults tended to spawn in specific fry outplanting areas (Blackett 1979). Lister et al. (1981) cited several examples in Alaska and British Columbia where wild coho stocks returned as adults to spawning areas from which they emerged as fry rather than areas from which they migrated as smolts. Symons (1969), Allee (MS 1974) and Glova (1978) observed that hatchery-origin juveniles often do not disperse readily from a release site and need to be physically scattered in a system. In Atlantic salmon transplants in Maine, juveniles are dispersed throughout the recipient watershed and in the best rearing habitat to increase chances of survival (K. Beland, pers. comm.). Fenderson et al. (1968) and Dickson and MacCrimmon (1982) noted that where natural colonization is required, the release of swim-up fry may increase area utilization compared to pre-smolt releases, with the added advantage of production of a population with more natural behavioral responses. Reisenbichler and McIntyre (MS 1986) recommended scatter-release of juveniles when seeding a barren area with rearing potential, in order to avoid excessive localized densities and resultant competition. They cautioned that dispersal of outplanted juveniles can be affected by water flow, with dispersal expected to be poor at stable low flows and to be excessive in a downstream direction at high flows. Blackett (1979) suggested that in colonizing a barren area with sockeye, adult dispersal in the recipient watershed may be encouraged by releasing fry and adults into the lake rather than into potential spawning tributaries, and by barricading the lake outlet with a weir to retain the adults. This approach, used successfully in the Frazer Lake sockeye transplant, should encourage adults to spawn in the previously unutilized tributaries of that lake system.

Based on the above, we recommend that in cases where at least some natural propagation is desired, tranplanted eggs and juveniles should be scatter-planted in order to minimize mortality from overcrowding and to maximize the utilization of natural spawning and rearing areas. Adults may be released into lakes with temporarily barricaded outlets to encourage natural dispersal. The decision of whether to release fish at specific sites or randomly will depend on the adequacy of available physical data showing those areas suitable for spawning and rearing, on our ability to discern accurately "prime" areas, and on the available access to those areas.

C.9. MINIMIZING PREDATION AND COMPETITION

Anadromous salmonids probably suffer greater mortality compared to non-anadromous fish such as landlocked chinook, sockeye (kokanee) and coho since fish that remain in freshwater have relatively few predators to contend with beyond a certain size. Lear (1975) observed that the number of predators in the stream and estuary will influence the minimum number of fry required to produce a self-sustaining stock. Therefore, where predator numbers are high, outplants of large numbers of juveniles will be required if depensatory mortality occurs. If this theory holds, larger outplants will experience proportionately lower losses since the predator population can only take a fixed number of prey in time. Reisenbichler amd McIntyre (MS 1986) observed that release of juveniles at times and sizes that will ensure their immediate migration to sea should greatly reduce freshwater losses. Hartman et al. (1967) and Heard (1978) noted that predation may be reduced by stocking larger fry at a time of abundant natural food to promote rapid growth. In lake stocking programs with sockeye, Koenings and Burkett (MS 1985) recommended optimizing fry stocking densities since juvenile growth is density dependent, affecting smolt size and age.

Hartman et al. (1967) also noted that during sockeye migrations of fry to nursery lakes and of smolts to sea, the juveniles are often subjected to intense predation by birds and fish. This predation is greater for smolts migrating in multi-lake systems where the migration pattern tends to be irregular and extended, compared to smolts migrating in single-lake systems where a regular and rapid migration pattern prevails. Therefore, the length and nature of the downstream travel route may also affect juvenile survival by extending the period of exposure to freshwater predators.

Several studies have shown that transport of juvenile salmonids to downstream release sites can be beneficial to marine survival. In the United States, the National Marine Fisheries Service has been conducting experiments since 1965 to determine the effect of downstream transport on salmonid homing and survival; the aim was to reduce migratory losses associated with dam construction on the Columbia River system (Ebel 1980). These studies showed that returns (catch and escapement) of chinook were increased 1.5-3 times (Ebel et al. 1973) and of steelhead 1.1-15 times (Ebel 1980) by transporting migrating juveniles by truck about 300-400 km down the Columbia River past several dams for release below Bonneville Dam. Return rates varied with species and environmental conditions in the river prior to transport. Homing ability was not diminished by this operation, and transported fish showed less than 0.2% straying from the area of juvenile capture (Ebel 1980). Apparently sufficient imprinting had occurred prior to juvenile transport to allow for good adult homing despite partial disruption of the freshwater migratory route. In these experiments, captured juveniles represented wild and hatchery stocks, were actively smolting at the time of capture, and had considerable stream experience having travelled up to several hundred kilometers in the Columbia River system before being collected.

In 1977, approximately 3.5 million chinook, coho and steelhead juveniles were transported in two cargo tank barges down the Snake and Columbia Rivers past as many as eight dams, and released below Bonneville Dam in the lower Columbia River (McCabe et al. 1979). During the transport operation which lasted 30-34 hr and covered up to 520 km, fresh river water was pumped continuously through the barges. Transport mortality of hatchery juveniles was estimated at less than 0.5%. The above authors observed that barging may be an effective method of transporting large numbers of migrating juveniles to bypass river obstacles such as dams without reducing adult homing success.

Later research on the Columbia River was expanded to include coho and sockeye, and the results confirmed the return benefits from transporting migrating juveniles downstream by barge or truck (U.S. Army Corps of Engineers 1985). An active transport program is presently conducted on the Columbia River system to enhance the depleted salmonid resources in that area. Between 1981 and 1984, about 31 million juveniles were barged downstream and released below the Bonneville Dam (U.S. Army Corps of Engineers 1985).

In Oregon, attempts are made to reduce nearshore predation by sea birds on hatchery-produced coho juveniles by barging smolts about 25-30 km offshore for release (W. McNeil, pers. comm.). Visual examination of released smolts indicated that they are healthy and robust.

In Sweden, Atlantic salmon smolts have been floated downriver in cages and released in estuaries to avoid freshwater losses (Sutterlin and Merrill 1978).

In Norway, studies on survival of Atlantic salmon juveniles during transport have been conducted since 1973 (T. Gunnerød, pers. comm.). In one study, Gaula River Hatchery smolts were transported by truck to Surna River located in a different fjord system. After a short imprinting period in that river, fish were transported varying distances in the marine environment using a live-well barge with a continuous water exchange. The largest gains in survival were noted for releases made past the Surna River estuary but survivals continued to increase, doubling or tripling the normal rate, for releases made as far as 60-80 km from the river mouth and 20 km offshore. Adult straying to other rivers in the area rose to 50%, but this was attributed to insufficient imprinting period in fresh water.

The above findings suggest that barging of transplanted hatchery smolts to sea will result in increased survival due to reduced freshwater and estuarine mortality. However, imprinting of transported juveniles to the new river has to be sufficient to result in good adult homing to the release area, thereby facilitating fishery management.

In summary, competition and predation may be reduced by manipulating size and release timing of hatchery juveniles, planting density and release location (Wash. Env. Foundation 1983).

The following measures are recommended to increase transplant success by reducing freshwater competition and predation:

a. Select a receiving system with limited numbers of competitors and predators (see section B.9).

b. Select a system with a short migration route, thereby reducing exposure to predators.

c. Where juvenile releases are contemplated, use large-scale transplants in order to achieve lower predation rates.

d. Stock larger fry at a time of abundant natural food to promote rapid growth and thereby reduce predation.

e. Release juveniles at times and sizes that will ensure minimum delay in migration to sea.

f. Where possible, release juveniles from a coastal or offshore release site to minimize the freshwater and estuarine migratory losses.

C. 10. IMPRINTING TECHNIQUES

Straying is probably one of the major reasons for failure of anadromous salmonid transplants compared to the relative success achieved with non-anadromous species such as kokanee (Appendices 18-21), Kamloops trout in British Columbia (Larkin 1954), and rainbow trout in New Zealand (Ayson 1910). Homing of salmonids can be very precise. Quinn and Fresh (1984) reported a homing accuracy of up to 99% for hatchery chinook while Hartman and Raleigh (1964) observed a 95% homing accuracy into lake tributaries for sockeye. However, straying from natal streams is also relatively common. Shapovalov and Taft (1954) observed a natural straying rate of 15-27% for coho in two coastal California streams located about 8 km apart, while Simon (1972) found that straying by chinook from individual Columbia River hatcheries to other streams within a 64 km radius averaged 15% and was as high as 83%.

Homing cues used by returning salmon in the open ocean are poorly understood but both genetic and environmental factors appear to be involved, with olfaction playing a key role in the home stream recognition (Lister et al. 1981; O'Connell et al. 1983; Quinn and Fresh 1984). Brannon (1981) stated that "homing behavior in Pacific salmon appears to be a response to odors acquired as juveniles, that are related to the environmental chemistry unique to their particular habitat". He suggested that initial imprinting on the natal stream probably occurs before emergence and certainly before leaving the incubation site. Imprinting continues during subsequent freshwater rearing and is sequential at least through the smolt stage. His theory suggests that when transplanting salmon eggs, fry, or fingerlings, partial imprinting may occur at any holding site.

In addition to olfactory cues, other factors affect the homing behavior of salmon including ecological conditions such as temperature, flow and turbidity (Quinn and Fresh 1984). A review by W. Heard (pers. comm.) of short-distance coho transplants in Alaska, concluded that "without suitable stream habitat, homing is short-lived and straying quickly follows". Other factors affecting homing behavior involve hatchery practices such as size and age at release, the relative nature and location of rearing and release sites, and artificial imprinting. Homing may be especially complicated in sockeye salmon due to their additional lake residence (Williams MS 1985).

While accurate homing is essential for stock differentiation (Saunders 1981), effective habitat utilization, and transplant success, straying may be an important tool for recolonizing unoccupied areas and extending the species range (Lister et al. 1981). For example, straying played an important role in the spread of pink salmon from the one tributary in Lake Superior where they were introduced, to some 43 streams throughout the Great Lakes over a 20-yr period (Emery 1981). Also, extensive straying of pink salmon transplanted to the Kola Peninsula in northeastern USSR resulted in widespread distribution of this species in the surrounding area (Kossov et al. 1960; Ricker 1972). However, Hartl (1980) and Lister et al. (1981) cautioned that any sustained increase in the rates of straying and resultant interbreeding between stocks could reduce genetic divergence and ultimately the genetic fitness of stocks.

Possible methods for reducing the straying of transplanted fish include the following:

a. Genetic selection. Returning progeny from a transplant should be used as broodstock for the succeeding generations (Thorpe 1980). In a distant transplant of chinook from a lower Columbia River tributary to Deschutes River in Puget Sound, the second generation transplant progeny returned to the recipient site much more successfully than did the first generation (return ratios of local Deschutes stock to transplant progeny of first and second generation were 11:1 and 4:1 respectively; Ricker 1972).

b. Hybridization. Homing may be improved through genetic manipulation whereby the few initial returns from a transplant are crossed with the pure donor stock (Lister et al. 1981). Experiments with chinook by Brannon (J. Woodey, pers. comm.) and with pink salmon by Bams (1976) showed that the hybrid stocks homed about four times better to the new site compared to the pure, non-local stocks. Therefore, in developing the broodstock, males, including jacks, from the initial successful returns may be used to fertilize donor females, thereby improving homing success. Examples of successful hybrid transplants in British Columbia include chinook in Chemainus River (Appendix 4) and sockeye in Upper Adams River (1980 and 1984 broods; Appendix 14).

c. Imprinting. Imprinting is a frequently used tool to improve the homing behavior of salmon (Snyder 1931; Thorpe 1980). Recent experiments with salmon in Oregon, Washington and New Brunswick have shown that imprinting can be achieved also at seawater release sites (Thorpe 1980). Such imprinting could improve the success of a terminal fishery and ensure that the returns concentrate in an area where wild stocks are least likely to be intercepted.

Lister et al. (1981) reviewed the literature on salmon homing and concluded that no clear guidelines existed as to the type and length of imprinting required to produce a high rate of homing to an off-station release site. However, the length of exposure to the release site appears to be an important factor. Some theories suggest that the critical imprinting period is species- and stock-specific, and that imprinting is most successful at the smolt stage (Lister et al. 1981).

Buxton and Schubert (DFO Info Memo. No. 105, Dec. 1984) found that hatchery-produced coho smolts from the 1980 broodstock, released into their home streams in the Chilliwack watershed, showed a similar rate of homing as adults to release streams despite a range in holding periods of 0-13 days. Thus 13-26% of the Dolly Varden Creek tags were recovered in that stream, located 29 km upstream of the hatchery; and 21-22% of the Salwein Creek tags were recovered in Salwein Creek located 26 km below the hatchery. In addition, the above release groups showed similar return rates (tag recoveries 70-83%) to the Chilliwack hatchery. Buxton and Schubert concluded that length of holding for imprinting at release site did not significantly influence coho homing to the release stream. Lister et al. (1981) cited examples where coho and steelhead hatchery smolts were imprinted to a release site within a few hours or days. D. Ortman (pers. comm.) observed that in chinook transplants in Idaho, release of chinook smolts into the receiving drainage resulted in immediate outmigration, but imprinting was sufficient for a "good" homing.

D. McNeil (pers. comm.) reported that 1983 brood chinook smolts reared in the Kitimat hatchery and released without holding into the Dala and Kildala parental rivers yielded recoveries of 51 and eight jacks in the respective streams in 1985. Of the eight recoveries made in the Kildala River, six had Kildala tags and no Kildala tags were recovered in the Kitimat system that year. The hatchery smolts released into the Dala River were unmarked so that the 51 recoveries made in that stream could not be identified as to origin. These preliminary data indicate that hatchery chinook smolts released without holding into the parental streams will home to those release streams and not return to the hatchery system where they were incubated and reared. In this example, the distance between the Kitimat River where the hatchery is located and the recipient streams is approximately 30 km, whereas the estuaries of the Dala and Kildala Rivers are about 9 km apart.

In the Tlupana Inlet system in British Columbia, similar chum adult returns were observed from on-site parental stream releases of 1 g hatchery fry from the Conuma hatchery, and from point releases into inlet parental streams outside the hatchery watershed (T. Perry, pers. comm.). In this case, homing of chum to release streams was apparently unaffected by the different imprinting strategies (i.e. on-site release from the hatchery versus off-site release without holding).

Little information is available on sockeye imprinting requirements. I. Williams (pers. comm.) recommends that where incubation facilities are not available at the receiving site, adult homing may be improved by transplanting at the alevin stage so that imprinting may commence early in the life cycle. A successful example of this technique was the transfer of 1984 brood sockeye alevins from the Cultus Lake hatchery to the Adams Lake for the Upper Adams River transplant (Appendix 14).

Lister et al. (1981) suggested that where a natural rearing area is available, the imprinting period may be extended to improve homing of transplanted chinook, coho and steelhead by outplanting fry and fingerlings rather than smolts. This approach requires preliminary survey of the candidate receiving watershed to determine the type of rearing area available and the juvenile carrying capacities (Lister et al. 1981).

Based on the above review, we recommend a short-term imprinting period of 2-3 d for chinook and coho smolts transplanted within 100 km of the donor stream, with release sites preferably located a considerable distance upstream of the receiving stream mouth in order to allow further imprinting during smolt outmigration. For more distant chinook and coho transplants, 2-3 wk of smolt imprinting is advisable. Where sufficient good rearing area is available, we recommend outplanting of younger chinook and coho stages (fry and fingerlings) to provide an extended imprinting period. This approach would require considerable amount of information on the receiving system. For sockeye, a considerably extended imprinting period is recommended, with transplants conducted at the egg or alevin stage.

d. Selection of release sites. Lister et al. (1981) observed that homing was most accurate for smolt releases from hatchery sites, with only about 2-3% straying observed. They found strong evidence in the literature that wild adults generally return to spawning areas where they emerged as fry, and not to where smolt migration was initiated. Therefore, homing of transplants could be improved by on-site constructon of a hatchery for direct release of juveniles into the receiving stream. This approach is used in the chinook transplant programs in the Capilano River in British Columbia (Appendix 2) and in the Wind River in Washington (Appendix 8).

The sequential imprint hypothesis suggests that the returning adults follow a chain of olfactory or other cues received as juveniles and recalled in reverse order by upstream migrants (Lister et al. 1981). Therefore, for transplants within a watershed, homing success to the release site may be improved by selecting a release site below rather than above the hatchery. This was recently demonstrated with coho transplants in Oregon (T. Nickelson, pers. comm.). Homing to the release site within a watershed also can be improved by using upstream compared to downstream donor stocks. Ricker (1972) observed that in chinook transfers in the Columbia River watershed, transplants from upstream to lower river areas were more successful than transplants of lower stocks upstream. This seems reasonable since the upriver stocks have to negotiate the downriver water course (Ricker 1972).

Another strategy employs the selection of release sites that are distant from the hatchery (Lister et al. 1981). It appears that in distant releases (eg. to another watershed) the "imprint chain" may be entirely broken, thereby causing the adults to return to the release site rather than to the hatchery site. However, it is important that returning adults not pass the hatchery closely during their migration to the release site, as they may be attracted into the hatchery.

e. Release of large numbers of juveniles. Quinn and Fresh (1984) and Sholes and Hallock (1979) found that for chinook, higher homing success was associated with larger returns. This suggests that some social factor acts as a motivational homing force. It was suggested by W. Heard (pers. comm.) that larger numbers of precisely homing coho adults may "decoy" smaller numbers of weakly imprinted fish.

C. 11. USE OF RETURNING PROGENY OF TRANSPLANTS

Usually, the transplanted stock produces very few initial returns. In order to hasten the development of a viable stock that is genetically adapted to the new site, the following recommendations are made (note that these strategies are also important for improving the homing success; see section C.10):

a. Carefully nuture the initial returns through artificial propagation to ensure high egg-to-release survival. The initial returns represent the few progeny of the donor stock which have the genetic characteristics required to survive in, and home to, the new environment. The likelihood of their progeny returning is almost certainly greater than that of the original donor stock (Brannon 1967; Vernon 1982). Ricker (1972) found that the second generation of chinook originating from the Little White Salmon River transplant to the Deschutes River in Puget Sound (Fig. 1) produced greater returns than the first generation. In Alaska, where up to seven non-endemic coho stocks may be used to develop a productive run, the few returns that come back are selectively used for broodstock (Heard 1978). Similarly, in steelhead transplants into the Willamette River in the Columbia River basin, only the successfully returning progeny of transplants are used as donor stocks; this approach avoids the dilution of the acclimated gene pool with new, less adapted donor stocks (D. Buchanan, pers. comm.).

b. Practice hybridization between the initial returns and the original donor stocks in order to increase production while retaining the genetic components of the first few surviving returns. Bams (1976) observed that the hybrid progeny resulting from crossing the non-local donor females with males from the initial transplant returns should be more successful in homing behavior than the pure donor progeny. In building up the depleted chinook run in the Chemainus River on Vancouver Island, very successful returns were observed from crossing the nearby Cowichan River donor females with the local Chemainus males (Appendix 4). Similarly, the 1980 and 1984 brood sockeye transplants in the Upper Adams River utilized hybrid crosses between Upper Adams males and nearby Cayenne Creek females (Appendix 14).

C.12. USE OF INNOVATIVE HATCHERY PRODUCTION TECHNIQUES

In the past several years, great strides have been made in the area of artificial propagation of Pacific salmon. In Canada and the United States, numerous experiments are underway to develop strategies for optimizing adult returns. Many of these experiments are still in progress awaiting final adult returns. Much of the current research deals with selective breeding for traits that maximize production such as growth rate, disease resistance, efficiency of food conversion, flesh quality and adult weight (FFI 1985d; Reisenbichler and McIntyre MS 1986). Norway has been studying the genetic variability of different strains of Atlantic salmon since the early 1970s with expectations that selective breeding will greatly profit aquaculture programs (FFI 1985d). In sockeye transplants involving the use of pure and hybridized stocks, Brannon (MS 1970) suggested that a kokanee population may be used to add a desirable genetic component, such as spawning timing, to the new sockeye broodstock.

Other research topics include developing a rapid sex differentiation method to permit early harvest of surplus males thereby providing good market quality, while holding females to maturity as broodstock to increase egg yield; producing largely female offspring to increase the potential egg-take from a particular broodstock; using sterile fish to avoid interbreeding of hatchery and wild fish stocks and avoid meat quality deterioration with maturation; and using hormones for artificial acceleration or deceleration of maturation and spawning (FFI 1981c, 1984a, 1985d; Reisenbichler MS 1986). For example, the USSR hatcheries involved in pink salmon colonization of the Kola Peninsula, practise extensive hormonal treatment of broodstock to regulate the reproductive process (Persov et al. 1984).

Research on successful hatchery rearing is directed at production of high quality juveniles at a reasonable cost. In Alaska, several new strategies are being developed for sockeye production (K. Johnson, pers. comm.). One approach involves the production of 0+ smolts to be reared in salt water until release. Alaskan researchers also plan to circumvent hatchery losses from IHN by developing a virus-free sockeye broodstock and releasing IHN-free juveniles (SSRAA 1983b). Another simpler approach involves the release of emergent sockeye fry directly into barren lakes, thus minimizing IHN outbreaks.

At the University of Washington, a diagnostic test has been developed to measure thyroid hormone levels to determine the correct release timing of salmon juveniles (FFI 1981c, 1985b). Elsewhere, methods are being developed to improve imprinting by using chemicals, such as morpholine, to increase homing accuracy to release sites (Harache 1979).

In Norway and Nova Scotia, economic benefits are reaped by accelerating the rearing of Atlantic salmon from two years to one year (FFI 1984e). At the University of Washington, a hatchery sustained coho run consisting largely of 2-yr-old adult spawners was developed through the release of accelerated 6.1-16.3 g 0+ juveniles (Brannon et al. 1982). Releases from 1973 to 1978 brood years yielded returns of 2.7-6.4%. In British Columbia, attempts to accelerate coho development during rearing produced a few returns (3.3% total returns for accelerated smolts versus 47.5% for normal smolts; Bilton and Jenkinson 1980). Unless the return rates can be greatly increased, this technique has little merit for reducing coho production costs. However, there is some evidence that accelerated rearing of chinook may be possible without significant reduction in marine survival (T. Perry, pers. comm.). The experiment involved chinook in Squamish River, British Columbia, which normally migrate as yearlings compared to chinook in Capilano River which normally migrate as 90-d smolts. In the fall of 1978, Squamish chinook eggs were transported to the Capilano hatchery for accelerated incubation and rearing. The resulting 90-d, 4.6 g smolts were returned to Squamish River the following May. At the same time, 90-d, 5.3 g Capilano smolts were released in the Capilano River. Survival to fisheries was comparable for the two release groups (0.50% for Squamish chinook and 0.62% for Capilano chinook) suggesting that accelerated chinook rearing may be a viable tool for reducing chinook production costs.

C.13. REGULATING FISHING PRESSURE

Regulation of fishing pressure during the initial stages of the transplant program is very important in building up the broodstock. For example, the establishment of the Frazer Lake sockeye run in Alaska was facilitated by an annual restriction of the commercial fishery (R. Blackett, pers. comm.). Likewise, the large escapement to the Upper Adams River in 1984 was partly attributed to fishery restrictions (Williams MS 1985).

STUDY NEEDS

FEASIBILITY STUDIES

Having selected candidate donor stocks and receiving systems, the following preliminary surveys are recommended:

1. Evaluate spawner distribution and potential sites for broodstock capture on the donor system.
2. Assess existing infrastructure in both systems, and its adaptibility and availability in support of the transplant program.
3. Evaluate the freshwater and local marine environments at the recipient site for biophysical characteristics including temperature, flows, water quality and food resources.
4. Evaluate freshwater spawning and rearing (streams and lakes) capacity of the recipient system considering stocking density and timing.
5. Evaluate the distribution and abundance of potential competitors and predators in the recipient system.
6. Compile disease profiles for both donor and recipient systems.
7. Assess physical suitability of nearshore area for terminal fishery and the degree of potential interception of wild stocks in that area.
8. If necessary, conduct bioassays in the recipient system.

ASSESSMENT STUDIES

Many aspects of sockeye and chinook freshwater population biology are imperfectly understood and lack quantitative definition (Vernon 1982). Therefore, a transplant program must be monitored to evaluate success or failure, establish reasons for the outcome, and determine the required modifications to the program (Blackett 1979; Vernon 1982; Reisenbichler and McIntyre MS 1986). Most of the earlier transplant evaluations provided only basic assessment data such as adult return rates and migration timing and size, without further analyzing for possible reasons to explain the outcome of the transplant. More thorough program evaluation should be provided through differential marking of release groups (Anon. MS 1982) and systematic monitoring through the various life stages. Blackett (1979) observed that continued success of the Frazer Lake sockeye transplant may be affected by long-term changes in lake productivity, smolt production, escapement goals and management strategy. He noted that data on size and condition factor of sockeye smolts may indicate the lake's rearing potential; a large smolt size may suggest probable underutilization of the lake and a small size may indicate some factor limiting to production. Examples of assessment studies of various successful chinook and sockeye transplants are given in Appendices 8, 9, 16 and 17.

SUMMARY

Transplant guidelines for establishing natural, self-sustaining runs are demanding and require that an extensive list of factors be considered such as the nature and availability of spawning and rearing habitats, migration distances and mortality factors during the freshwater phase. Some of the guidelines are inherently conflicting; for example, maximizing survival to smolt stage versus planting out at egg or early fry stages to minimize disease and maximize natural behavior. The transplant guidelines become much less difficult where artificial propagation can be used to establish and maintain the run, since control can be exerted even to early marine rearing. In addition, since the survival of hatchery juveniles to the smolt stage may be 10-100 times higher than that of wild juveniles, larger outplants can be produced from fewer brood fish. Potential homing problems can be reduced as the adults need only travel as far as the terminal fishery or hatchery site, foregoing any complex freshwater routes. Therefore, in transplants geared towards ocean ranching (ie, the new Fishery Development concept), only three major demands must be met: an adequate supply of eggs, good marine survival and accurate homing to the release site.

The tentative guidelines for successful salmon transplants are summarized below. Although these guidelines were developed from review of successful transplants of sockeye, chinook, coho, chum, pink and Atlantic salmon, all of the guidelines can be applied in various degrees to chinook and sockeye transplant programs. The guidelines listed below are relevant to projects where at least a partially self-sustaining run is to be developed. Where introductions are dependent on artificial propagation, such as the new Fishery Development concept or other forms of ocean ranching, less attention can be given to those guidelines marked with an asterisk.

A. CONSIDER THE FOLLOWING CHARACTERISTICS IN SELECTING SUITABLE DONOR STOCKS.

1. Geographical proximity to the receiving system; systems should be no more than 100 km apart, as measured between river mouths along connecting bodies of water.

2. Good access to broodstock in the donor system; consider what infrastructure is suitable and available to support the operation.

3. Sufficiently strong escapement for long term egg-takes; presuming a minimum annual transplant of 1 million eggs and a 10% removal from a donor stock, a minimum mean escapement of 1,340 chinook and 2,220 sockeye would be required for each of three donor stocks.

4. Matching biological and environmental characteristics:

   * a) matching life history types,

   * b) matching migration and spawning timing relative to the recipient temperature regime,

   * c) matching freshwater migration distance and route orientation,

   d) matching marine conditions,

   * e) other criteria developed especially for coho salmon: do not mix coastal and interior stocks; do not mix stocks from large stable rivers with stocks from small unstable rivers; do not mix stocks from north and south of Campbell River on Vancouver Island.

5. Disease profiles should match or at least not place either system at risk.

6. Ability to retain fish quality for a considerable period of migration (upstream stocks are better).

7. Ocean distribution and migration timing that will best serve the demands of user groups and facilitate fisheries management.

B. CONSIDER THE FOLLOWING CHARACTERISTICS IN SELECTING SUITABLE RECEIVING SITES.

1. Availability of suitably matched donor stocks.

2. Isolation from wild salmon stocks.

3. Good access to release sites and availability of suitable infrastructure.

*4. Suitable freshwater environment for spawning and rearing.

*5. Suitable forage base.

*6. If the receiving site is barren of anadromous salmonids, a physical barrier obstructing access to the receiving site should be the only apparent cause.

7. Suitable water source for holding juveniles prior to release.

*8. Appropriate length (preferably short) and orientation of the freshwater migration route.

*9. Limited predation and competition for food and space.

10. Suitable marine environment.

11. Suitable terminal fishing site.

C. SELECT APPROPRIATE FISH CULTURE, RELEASE, AND FISHERY STRATEGIES.

1. Conduct large-scale and long-term (up to 10 yr) outplants involving a minimum of 1 million eggs annually until significant returns are developed. For more rapid development to production-oriented levels, much higher releases should be made.

2. Provide a large gene pool. The suggested minimum would be three donor stocks and their hybrids for a total of nine genetic groups.

*3. Transplant a combination of life stages.

*4. Use appropriate transfer and planting methods for eggs, juveniles, and adults.

5. Release juveniles at appropriate size (larger size is generally better).

6. Release juveniles at appropriate time.

7. Acclimate juveniles to the release site.

*8. Ensure adequate dispersal of transplanted fish.

9. Limit predation and competition during the freshwater phase.

10. Use techniques that improve homing to the release site.

11. Make optimal use of the returning progeny of transplants.

12. Develop and use innovative hatchery production techniques.

13. Regulate the fishing pressure.

D. CONDUCT FEASIBILITY AND ASSESSMENT STUDIES AT A LEVEL ADEQUATE TO DEFINE REASONS FOR SUCCESS OR FAILURE OF THE PROJECT

All of the above guidelines are considered to be important in establishing successful, production-oriented transplants. However, the three key factors which appear to have most often governed transplant success are massive outplants, persistence of the transplant effort, and the release of large and healthy juveniles.

Table 7 summarizes the transplant criteria met and the methods used in successful salmon transplants reviewed in this report. Examples with insufficient data and recent unassessed programs were excluded from this summary. The two most notable features in the summary are that the majority of

Table 7. Summary of transplant criteria met and methods used in successful salmon transplants ('X' indicates 'YES'; abbreviations are explained in a box below)[a].

TRANSPLANT	DONOR STOCK				RECEIVING SYSTEM								TRANSPLANT METHODS								
	Geographic proximity	Access & infrastructure	Broodstock abundance	Biol. & env'tl match	Suitable donor	Access & infrastructure	If barren, barrier only	Spawn. & rearing capabilities	Forage[b]	Limited compet'n & pred'n[c]	Suitable Fw migr. route	Marine environment	Hatchery sustained/supplemented	Large-scaled	Long-term	Large gene pool	Size at release	Acclimation[e] (Homing)	Active dispersal	Nurture progeny returns	Other
CHINOOK																					
Capilano R.	X	X	X			X	UFH		X	X	X	X	X		X		5 g	X		X	
Little Qual. R.	X	X	X	X	X	X	UFH		X	X	X	X	X	X	X		5.8 g	X		X	
Chemainus R.	X	X	X	X	X	X	X		X	X	X	X	X		X		7 g	X		X	HY
Michigan L.		X	X	?[f]	?	X	NA	X	X	X	NA	None	X	X	X	X	5 g	X	X	X	
Frazer R.	X	X	X	X	X	X	X*[g]	X	X	?	X	X					Reared	X			
Wind R.	X	X	X	X	X	X	X*	X	X	X	X	X	X	X	X	X	Age 1+	X		X	
Willamette R.	X	X	X	X	X	X	X*	X	X	X	X	X	X	X	X	X	5-7 g	X	X	X	
Coeur d'Alene L.		X	X	?	?	X	NA	?	X	X	NA	None	X		X	X	10-48 g	X			
Sakakawea L.		X	X	?	?	X	NA	?	X	X	NA	None	X	X	X	X	3-27 g	X	X		MOR
New Zealand		X	X	?	?	X	NA	X	X	X	X	?	X		X		?5g;to2/yr	X	X	X	
Chile		X	X	?	?	X	NA	?	X	X	X	?	X	X	X	?	4-70g	X	X	X	
SOCKEYE																					
Upper Adams R.	X	X		X	X	X	X*	X	X	?	X	X	X		X		0.2 g	X		X	HY/FR
Great Central L.	X	X	X	X	X	X	X*	X	X	?	X	X		X	X		E	X	X		
Frazer L.	X	X	X	X	X	X	X*	X	X	?	X	X		X	X		E/F/A	X	X		FR
Lake Washington	X	X	X	X	X	X	X*	X	X	?	X	X			X		0.2-8 g; to 1+	X	X	X	
KOKANEE																					
Great Lakes		X	X	?	?	X	NA	X	X	?	NA	None	X	X	X	X	E/F/Fg	X	X		
Koocanusa L.		X		?	?	X	NA	X	X	X	NA	None	X	Single accidental rel.			Fg	X		X	
COHO																					
Michigan Lake		X	X	X	X	X	NA	X	X	X	NA	None	X	X	X	X	25 g	X	X	X	
New Hampshire		X	X	?	?	X	UFH		X	X			X		X	X	28-45 g	X	X	X	
PINK																					
Great Lakes		X		?	?	X	NA	X	X	?	NA	None		Single accidental rel.			fg	X			
Puget Sound	X	X	X	?	?	X	NA	X	X	X	X	X	X	X	X		0.5-1.5 g	X		X	
Kola Peninsula		X	X	Artificial manipulation			UFH	X	X	X	?	?	X	X	X	X	Reared	X	?	X	HOR
ATLANTIC SALMON																					
Newfoundland, New Brunswick & Nova Scotia	X	X	X	X	X	X	NA	X	?	?	X	X	X				Unfed F	X	X	X	HY
	X	X	X	X	X	X	NA	X	X	X	X	X	X			?	0+,1+,2+	X	X	X	

[a] See text summary (p.46) for definition of criteria; disease criterion omitted due to insufficient information.
[b] Includes food provided during hatchery rearing.
[c] Includes shelter provided during hatchery rearing.
[d] Annual transplants/releases of 1 million or more eggs or fry.
[e] Includes on site hatchery incubation, rearing and holding.
[f] Insufficient information.
[g] Asterisk indicates that a fishway was constructed over barrier.

ABBREVIATIONS USED

(Size at Rel.)		(Other)	
A	Adult	FR	Fishery Regulations
E	Egg	HOR	Hormones
F	Fry	HY	Hybrids
Fg	Fingerling	MOR	Morpholine
		NA	Not Applicable
		UFH	Unsuitable/limited freshwater habitat

the transplants are hatchery-sustained or supplemented, and that all but the two single accidental releases have met half or more of the 19 criteria and methods which we consider to be important for transplant success.

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____ 1984c. Chile points the way to sea ranching off Falklands. April 11(4).

____ 1984d. Faroes look to ranching salmon established in five rivers. September 11(9).

____ 1984e. Atlantic salmon hatcheries will boost salmon stocks. October 11(10).

____ 1984f. Atlantic salmon smolts for the Baltic. November 11(11).

____ 1984g. Salmon ranching - Reseach programs in Scotland. November 11(11).

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APPENDICES

CHINOOK TRANSPLANTS

Numerous artificial plantings of chinook have been made into lakes and rivers worldwide but self-perpetuating stocks have been established in only a few cases. All known successful chinook transplants are detailed below in Appendices 1 to 13.

APPENDIX 1. CHINOOK TRANSPLANTS IN BRITISH COLUMBIA

General Synopsis

In British Columbia, the few instances of chinook transplants that have been fully assessed for adult returns indicate that hatchery-sustained transplants generally do as well as the donor stocks (eg. Big Qualicum transplant to Capilano River; Appendix 2) or even outperform the donor stocks (eg. Big Qualicum transplant to Little Qualicum River; Appendix 3). Likewise, the hybridized Chemainus/Cowichan chinook stock showed equally high returns to Chemainus River as the pure Chemainus stock. The above transplant successes are attributed largely to well-matched donor stocks characterized by geographic proximity to receiving sites (generally 100 km or less), similar length and orientation of the freshwater migratory routes, extensive rearing of juveniles at the receiving sites, and the relatively large release size of 5-7 g.

APPENDIX 2. CHINOOK TRANSPLANTS IN CAPILANO RIVER

Sources of information: DFO-SEP brood summaries; Marshall et al. 1976; Hancock and Marshall 1985.

Background

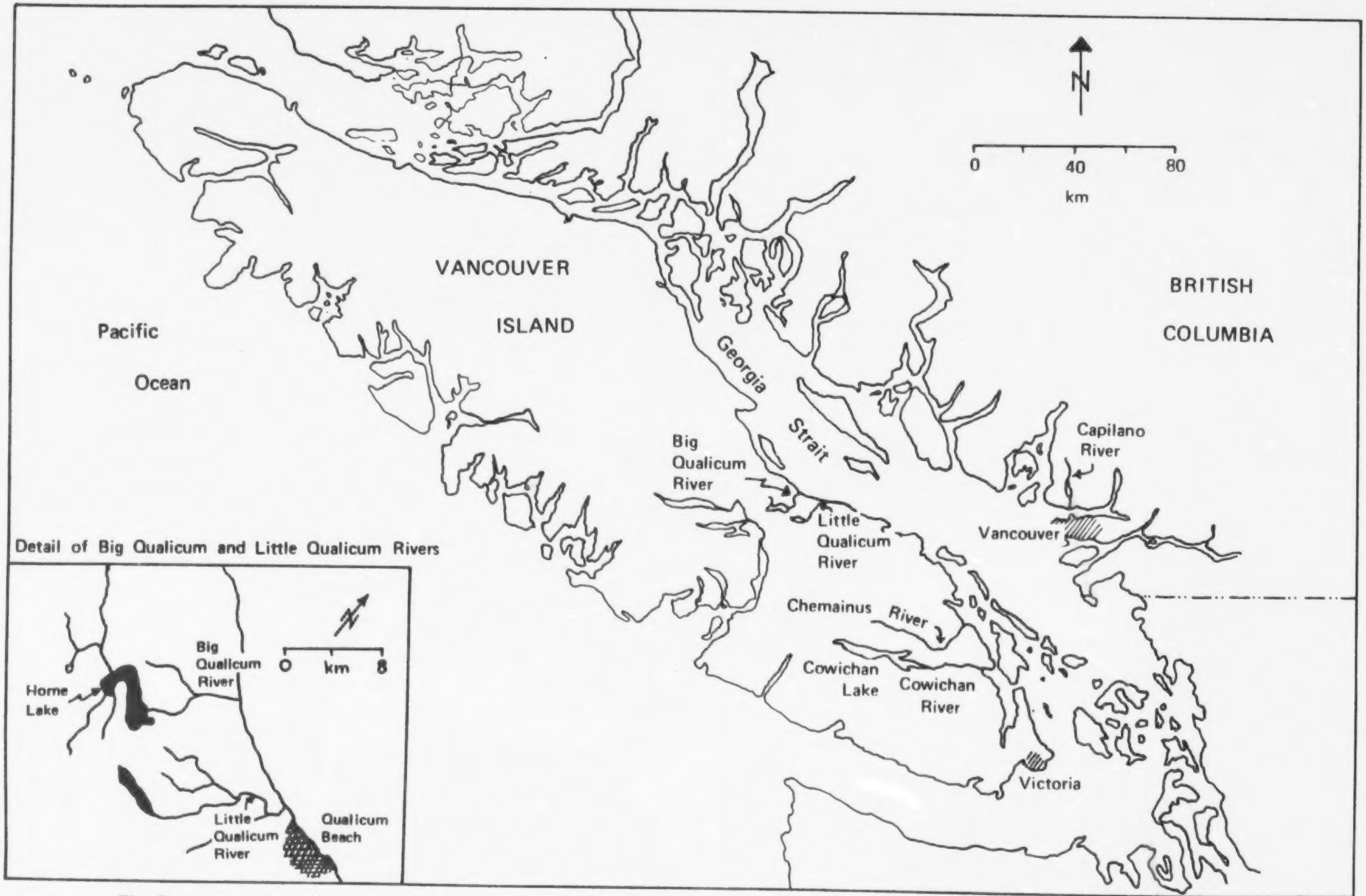
Historically, no natural chinook run existed in the Capilano River due to the very limited spawning area and cold water temperatures. In order to develop a chinook run to that system, Big Qualicum chinook have been transplanted to the Capilano River (Fig. 9) since 1968.

Transplant strategy

Chinook eggs were transported from the Big Qualicum hatchery to the Capilano hatchery for incubation and rearing. Juveniles were reared for several months at Capilano and released usually in June at about 5 g. The broodstock originally consisted of Big Qualicum River fish and was later supplemented with transplant returns to the Capilano River. Due to limited and unfavourable chinook habitat in the recipient system, the transplanted stock is sustained completely artificially through annual releases of juveniles from the Capilano hatchery.

Adult returns

Marine survival by brood year was compared for the Big Qualicum parental stock and the Capilano stock originating from both the direct Big Qualicum transplants and from returning transplant progeny to Capilano River (Table 8).


N
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COLUMBIA
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Pacific
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Georgia
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Capilano
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Big
Qualicum
River
Little
Qualicum
River
Chemainus River
Cowichan
Lake
Cowichan
River
Victoria
Detail of Big Qualicum and Little Qualicum Rivers
Home
Lake
Big
Qualicum
River
0 km 8
Little
Qualicum
River
Qualicum
Beach

Fig. 9. Location of Capilano, Big Qualicum, Little Qualicum, Cowichan and Chemainus Rivers in British Columbia.

Table 8. Comparison of marine survival for Big Qualicum resident chinook and Big Qualicum transplants to Capilano hatchery, British Columbia. [a, b]

	BIG QUALICUM HATCHERY				**CAPILANO HATCHERY**							
	Big Qualicum broodstock				Big Qualicum broodstock				"Capilano" broodstock[c]			
Brood Year	Date of Release	Size at Release (g)	No. Released	% Return	Date of Release	Size at Release (g)	No. Released	% Return	Date of Release	Size at Release (g)	No. Released	% Return
1971	Jul 10-21/72	6.1	166,262	2.20	Jun 19/72	5.1	338,150	0.39	-	-	-	-
1972	Jun 20/73	4.6	163,365	2.21	Jun 11/73	5.3	298,967	2.29	-	-	-	-
1975	Jun 11/76	6.7	836,617	3.09	Jun 17/76	5.9	435,412	1.60	Jun 17/76	5.2	47,908	1.74
1976	Jun 1/77	6.3	772,225	7.25	-	-	-	-	Jun 6/77	6.3	769,270	4.40
1978	Jun 4/79	5.3	1,147,911	0.25	Jun 7/79	5.8	190,763	1.42	May 11/79	5.3	279,780	0.62
1979	Jun 12/80	5.2	1,048,238	0.13	-	-	-	-	Jun 13/80	4.5	403,346	0.31

[a] From DFO-SEP brood summaries. Marine survival is defined as release-to-return survival calculated from catch and escapement data.

[b] Where several treatment groups were released from a hatchery (eg. different ponding and release dates and sizes at release) only similar treatments were selected from each brood year for comparison between hatcheries.

[c] "Capilano" broodstock are the progeny of earlier Big Qualicum transplants; the transplant of Big Qualicum chinook to Capilano was initiated in 1968.

Between year comparison was not made due to significant annual variations in marine conditions affecting sea survival (C. Cross, pers. comm.). Total returns (catch and escapement) for all three groups were roughly comparable indicating that even the first-generation transplanted stock experienced relatively successful marine survival and homing to the new environment. Chinook escapements to the Capilano River have grown from around 40 fish in the early 1970s to around 1,500 fish in the early 1980s (Table 9).

Suggested reasons for transplant success

Donor/recipient combination

The donor and receiving sites are relatively close, just over 100 km from each other across the Georgia Strait (Fig. 9). The returning transplant progeny therefore negotiate a similar ocean migration route as the parental stock. The freshwater migration route in both the donor and receiving streams is relatively short and uncomplicated (Fig. 9) and this probably facilitates juvenile and adult migration. Although chinook returning to the Big Qualicum and the Capilano Rivers must orient themselves in opposite directions in order to find the respective river outlets (Fig. 9), this apparently does not interfere with homing to the Capilano River.

Transplant strategy

Rearing entirely at the Capilano hatchery probably contributes to good homing by the returning adults. Adequate marine survival may be also attributed to the relatively large size (5 g) of juveniles at release.

APPENDIX 3. CHINOOK TRANSPLANTS IN LITTLE QUALICUM RIVER

Sources of information: DFO-SEP brood summaries; Hancock and Marshall 1985; T. Perry (pers. comm.).

Background

Historically, the Little Qualicum River (LQR) (Fig. 9) had a low escapement of approximately 400 chinook (Table 10) largely due to limited spawning area. In order to increase chinook production, a transplant program was initiated in 1980.

Transplant strategy

The original donor stock came from the Big Qualicum River (BQR) since the LQR chinook were few in number and were largely BQR strays. Since 1980, chinook eggs were incubated in the BQR hatchery and fry transported annually at ponding time to the newly constructed LQR rearing ponds. Fry were reared at the new site to around 5-8 g prior to release in May or June. In the last few years, the returning progeny were used for broodstock. The returns are also spawning successfully in the LQR chum spawning channel and probably in the river as well. However, no spawning surveys were conducted to confirm this.

Adult returns

The complete adult returns available for the 1979 and 1980 brood years indicate that the transplanted chinook outperformed the parental chinook (Table 11):

Table 9. Salmon escapement record for Capilano River, 1947-1985 (from Hancock and Marshall 1986; 1985 data from C. Cross, DFO).

YEAR	SOCKEYE	CHINOOK	COHO	CHUM	PINK	STEELHEAD
1947			3500	3500	7500	750
48			7500	1500	N/O	750
49			3500	1500	3500	750
50			3500	1500	N/O	1500
51			3500	3500	750	750
52			7500	1500	25	1500
53			3500	750	1500	750
54			3500	3500	75	1500
55	4		4998	400	400	95
56			1840	25		65
57			5100	200	75	95
58			3745	400	N/A	75
59			NO	RECORD		
60			3614	25		251
61			2114	25	25	86
62			2636	25		97
63			2071	75	100	97
64			2622	25		161
65			750	25	25	25
66			3500	25		75
67			1500	25		200
68			1500	200	N/O	25
69			1500	200	25	75
70			3500	75	N/O	75
71		44	4000	75	25	91
72		38	1200	700	7	91
73		165	1100	1100	150	56
74		93	40200	1500		31
75		767	6391	400	200	35
76	2	1102	25248	40	-	12
77		-	NO RECORD	120	30	150
78			500	250	-	35
79		3000	43000	280	200	100
81		1330	24100	400	450	200
82		463	27500	100	-	120
83	3	1133	20186	500	70	237
84		1694	16859	205	-	380
85		629	20854	N/A	N/A	N/A

Table 10. Salmon escapement record for Little Qualicum River, 1947-1983 (from Hancock and Marshall 1985).

YEAR	SOCKEYE	CHINOOK	COHO	CHUM	PINK	STEELHEAD
1947	N/O	25	3500	75000	N/O	UNK
48	N/O	N/O	3500	35000	N/O	UNK
49	N/O	N/O	3500	35000	25	UNK
50	N/O	200	3500	75000	400	UNK
51	N/O	200	3500	75000	750	3500
52	N/O	200	7500	35000	400	1500
53	N/O	750	3500	35000	200	3500
54	N/O	750	3500	35000	400	3500
55	25	1500	3500	35000	400	UNK
56	25	1500	3500	35000	400	1500
57	25	750	3500	35000	1500	1500
58	200	750	3500	35000	750	1500
59	25	400	1500	35000	25	1500
60	25	750	3500	35000	75	1500
61	25	400	3500	35000	75	1500
62	N/O	400	7500	35000	N/O	1500
63	N/O	750	3500	35000	75	1500
64	UNK	750	7500	35000	N/O	UNK
65	N/O	750	3500	15000	25	1500
66	N/O	400	7500	35000	75	UNK
67	N/O	350	1200	40000	N/O	UNK
68	200	425	3500	85000	25	UNK
69	75	400	1500	75000	N/O	UNK
70	25	400	3500	104775	75	UNK
71	25	750	3500	35000	N/O	UNK
72	75	400	400	50000	25	UNK
73	75	400	1500	75000	25	UNK
74	25	200	3500	65000	25	UNK
75	25	200	400	35000	25	UNK
76	200	400	3500	22500	25	UNK
77	25	75	3500	35000	N/O	-
78	45	30	5500	75000	-	-
79	100	25	2000	40000	-	-
80	100	N/O	4000	60000	-	-
81	20	10	1500	30000	-	-
82	20	1083	1000	66704	-	-
83		3000	2000	55000	-	-
84						
85						

Table 11. Comparison of marine survival for Big Qualicum resident chinook and Big Qualicum transplants to Little Qualicum, British Columbia.[a]

	BIG QUALICUM				**LITTLE QUALICUM**			
	Big Qualicum broodstock				Big Qualicum broodstock			
Brood Year	Date of Release	Size at Release (g)	No. Released	% Return	Date of Release	Size at Release (g)	No. Released	% Return
1979	Jun 12/80	5.2	1,048,238	0.13	Jun 6-12/80	5.1	1,299,912	0.84
1980	May 11/81	4.2	63,033	0.36[b]	May 27/81	4.5	1,178,257	0.43[b]

[a] From DFO-SEP brood summaries. Marine survival is defined as release-to-return survival calculated from catch and escapement data.

[b] Incomplete since 5 and 6-yr-old returns are not yet available.

	% ADULT RETURNS	
Brood	Little Qualicum	Big Qualicum
1979	0.84%	0.13%
1980	0.43%	0.36%

Although no quantitative data are available, there is evidence of chinook straying between the donor and recipient systems.

Suggested reasons for transplant success

Donor/recipient combination

The receiving site was historically capable of supporting chinook species as indicated by the presence of a small local population. The freshwater migration routes at the donor and receiving sites are relatively short and uncomplicated, and since the two systems are only about 9 km apart (Fig. 9), the ocean migration routes of the respective stocks are almost identical. Although the transplanted fish may pass the parental stream on route to the Little Qualicum River, they appear to home well to the new site. Finally, migration timing of the donor stock is similar to that of the Little Qualicum River native stock.

Transplant strategy

Juveniles were reared for 3-4 mo at the receiving site and released at 5-8 g. These two factors probably enhanced the homing accuracy and marine survival respectively.

APPENDIX 4. HYBRID CHINOOK TRANSPLANTS IN CHEMAINUS RIVER

Sources of information: DFO-SEP brood summaries; Marshall et al. 1976.

Background

Historically, the Chemainus River (Fig. 9) had a very low escapement of around 50 chinook (Table 12). In order to increase chinook production in that system, an enhancement program was initiated in 1979.

Transplant strategy

Since the Chemainus River chinook run was insufficient for broodstock development, the initial egg-takes were supplemented with a hybrid complement of Chemainus males and Cowichan River females (Fig. 9). The resultant pure stock and hybrid fry were reared at the Chemainus hatchery to about 7 g and released in June.

Adult returns

The hybrid chinook transplant produced very good adult returns which were equal to or higher than the pure stock returns (Table 13). It appears that the hybridization of the local Chemainus stock with the nearby Cowichan donor stock was not detrimental to the marine survival and homing ability of the

Table 12. Salmon escapement record for Chemainus River, 1947-1984 (from Marshall et al. 1976; data for 1976-1984 from DFO spawning files).

YEAR	SOCKEYE	CHINOOK	COHO	CHUM	PINK	STEELHEAD
1947		N/O	200	15000	N/O	1500
48		25	1500	35000	N/O	75
49		N/O	750	75000	N/O	400
50		N/O	7500	100000+	N/O	400
51		25	7500	75000	N/O	15000
52		N/O	3500	35000	25	7500
53		N/O	7500	35000	N/O	3500
54		25	7500	35000	N/O	3500
55		N/O	750	15000	25	1500
56		200	1500	7500	N/O	1500
57		25	3500	35000	N/O	1500
58		N/O	3500	35000	N/O	3500
59		N/O	400	3500	N/O	1500
60		N/O	400	3500	N/O	750
61		25	200	3500	N/O	75
62		25	400	3500	N/O	400
63		N/O	400	3500	N/O	200
64		25	400	3500	N/O	200
65		25	400	7500	N/O	200
66		200	400	35000	N/O	400
67		50	400	12000	N/O	300
68		100	100	12000	N/O	300
69		20	300	8000	N/O	200
70		16	400	3750	N/O	200
71		30	1200	3000	N/O	UNK
72		60	500	24500	N/O	UNK
73		65	450	24000	N/O	UNK
74		40	1800	20500	N/O	UNK
75		20	350	4500	N/O	UNK
76		60	200	3000		-
77		150	950	15000		-
78		261	310	17000		
79		225	450	16500		
80		90	300	15000		
81		1750	25	22700		
82		750	520	43600		
83		N/A	N/A	N/A		
84		275	300	35000		
85						

Table 13. Comparison of marine survival for Chemainus pure chinook stock and Chemainus/Cowichan hybrid chinook stock, British Columbia.[a]

	CHEMAINUS Pure Stock				**CHEMAINUS MALES X COWICHAN FEMALES** Hybrid Stock			
Brood Year	Date of Release	Size at Release (g)	No. Released	% Return	Date of Release	Size at Release (g)	No. Released	% Return
1979	Jun 8/80	6.8	28,407	5.60	Jun 8/80	6.6	79,709	5.92
1980	Jun 8/81	7.7	64,136	2.69[b]	Jun 8/81	7.7	42,828	2.63[b]

[a] From DFO-SEP brood summaries. Marine survival is defined as release-to-return survival calculated from catch and escapement data.

[b] Incomplete since 5 and 6-yr-old returns are not yet available.

resultant hybrid progeny.

Suggested reasons for transplant success

Donor/recipient combination

The Cowichan River is only about 25 km away from the Chemainus River and the length and orientation of the freshwater migration routes is similar for the two streams (Fig 9). The ocean migration routes are also expected to be similar due to the physical proximity of the two systems. Although the adults returning to the Chemainus River may pass the donor site, no problems were observed with straying to the parental stream.

Transplant strategy

A transplanted hybrid stock with half donor and half local genes is expected to have better survival than a pure donor stock (Bams 1976). The release of reared juveniles from the Chemainus hatchery at about 7 g favoured good marine survival.

APPENDIX 5. CHINOOK TRANSPLANTS IN GREAT LAKES

Sources of information: Aron and Smith 1971; Ricker 1972; Parsons 1973; Carl 1982; Withler 1982; Kwain and Thomas 1984.

Synopsis

Chinook were successfully introduced into the Great Lakes by planting approximately 6 million smolts between 1967 and 1970. Although natural reproduction is becoming common, annual hatchery releases heavily supplement the introduced runs. The transplant success, especially in Lake Michigan where a very successful recreational fishery was established, is attributed to several factors including suitable chinook habitat in the lake and tributaries, abundant food in the form of alewives, lack of competition from other piscivorous species except for the introduced coho, limited predation, systematic and sizeable outplantings of 5 g chinook smolts, imprinting of juveniles to the release sites, and the absence of a marine phase which precluded extensive straying and marine-related mortality. Lower survival in the other Great Lakes is attributed in part to scarce forage, predation by lampreys and lake eutrophication.

Transplant strategy

The early chinook introductions in the Great Lakes were made between 1873 and 1933 and involved approximately 11 million fry. Donor stocks came from B.C. rivers and the Sacramento River in California. The initial transplants prior to 1898 were characterized by numerous plantings of small lots of fry in a wide range of habitats. During that 26-year period, 8.8 million chinook fry were released from 237 outplantings with about 37,000 fry/plant. In 1950, the trend began toward planned, long-term introductions of chinook in a few selected waters using fingerling and smolt plantings rather than fry plantings.

From 1967 when the first successful chinook plantings were made until 1970, 6 million chinook smolts were released in the Great Lakes, with Lake Michigan receiving 69% of the smolts. Each of the 34 plants made during that period averaged 174,000 juveniles. Chinook were reared for about 4-5 mo and released in the spring at approximately 5 g. The majority of smolts were released at tributary mouths; some were released in small headwater streams of major tributaries, and in the Great Lakes themselves. To enhance homing to streams, chinook juveniles were held at release sites for 2-8 wk prior to liberation. Ponds and blocked stream sections served as temporary enclosures. However, homing seemed to be strong even for plants without holding, especially in Lake Michigan.

The Great Lakes chinook sport fishery is maintained through annual outplantings of hatchery juveniles. Eggs are taken from the returning broodstock, as well as from the Columbia River stocks which formed the original broodstock, and other Pacific chinook stocks. In addition to augmenting the egg supply, the Pacific stocks are used to increase the genetic diversity of the transplanted stocks.

Transplant returns

The 1967 to 1970 chinook plantings in the Great Lakes resulted in a successful sport fishery. Between 1968 and 1970, 381,000 chinook were captured by various means in the Great Lakes, with 91% of all recoveries made in Lake Michigan. Chinook in Lake Michigan showed excellent growth and a survival of up to 20%. In 1970, the first natural runs of landlocked chinook were observed in the Michigan tributaries, indicating that natural reproduction succeeded within the first few generations of recent transplants. Also of interest is that some of the established runs have modified their spawning timing from the fall timing which is typical of the west coast parental stocks, to the spring timing. This new strain was first observed in the Great Lakes in the spring of 1983.

Project assessment

Chinook transplants in the Great Lakes have been monitored since the 1950s. Juveniles are sampled for growth rate, and catch and escapement data serve as indicators of population size and survival. In addition, tributaries are surveyed to assess extent of natural spawning.

Suggested reasons for transplant success

Donor/recipient combination

An array of donor stocks, mostly from the Columbia River watershed, provided a broad genetic base for the initial and subsequent transplants thereby facilitating the process of natural selection. Lake Michigan and its tributaries showed the highest growth and survival and the strongest homing of transplanted chinook compared to other Great Lakes. This is attributed to suitable chinook habitat in the Lake Michigan tributaries, suitable habitat in Lake Michigan itself including favourable temperature and oxygen regimes, a strong forage base consisting mainly of alewives, the absence of competition by other large piscivorous species, limited predation by sea lampreys, good homing to release streams, and the absence of a marine phase which reduced straying and eliminated marine-related mortality. Lower transplant success was observed in Superior, Erie and Ontario Lakes, probably due to scarce forage, eutrophication in Lake Erie and severe lamprey predation in Lake Ontario.

Transplant strategy

Prior to 1950, chinook transplants in the Great Lakes consisted of numerous plantings of small lots of fry with about 37,000-60,000 fish/lot in a wide range of habitats. After 1950, larger plantings were made of about 174,000 fish/plant in a few selected waters. Also, while earlier, unsuccessful plantings consisted primarily of fry, later plantings consisted entirely of smolts released at about 5 g, after 4-5 mo of rearing. In addition, 2-8 wk were allowed for imprinting at the release site in order to improve homing. These changes in transplant techniques are summarized in Table 14.

APPENDIX 6. CHINOOK TRANSPLANTS IN FRAZER RIVER, ALASKA

Source of information: Blackett 1979.

Synopsis

A chinook run in the Frazer River system on Kodiak Island was developed by planting 160,000 fry over a 4-yr period between 1966 and 1969. Nearby Karluk Lake system located approximately 150 km from the Frazer system, provided the broodstock. The introduced run is still in the early stages of establishment but appears to be self-sustaining. It currently averages about 50-150 spawners each year.

Background

A natural chinook run did not exist in the Frazer River (Fig. 10) before the transplant program. Preliminary studies in the 1950s indicated potential spawning and rearing areas in the Frazer River system, and the only barrier to natural colonization with chinook appeared to be a 10 m high impassable falls below the Frazer Lake outlet.

Transplant strategy

The Frazer River chinook run was developed by planting 160,000 fry over a 4-yr period beginning in 1966 (Table 15). The nearby Karluk River (Fig. 10) provided the broodstock. The closer Red River also had a chinook run but was less accessible for broodstock collection. The eggs were flown from the Karluk River to the Kitoi hatchery on nearby Afognak Island (Fig. 10) for incubation to the fry stage. Fry were airlifted and released in the Frazer Lake outlet and below the Frazer River falls.

Transplant returns

The Frazer River chinook run is still in early stages of establishment and averages about 50-150 spawners each year at the fishpass (Table 15). An unknown number of chinook spawn in the river below the fishpass. The spawning grounds generally parallel the fry release sites indicating that, unlike the Frazer sockeye which have extended their range through straying (see Appendix 16), the Frazer chinook return specifically to fry release sites above the falls and in the lower river.

Project assessment

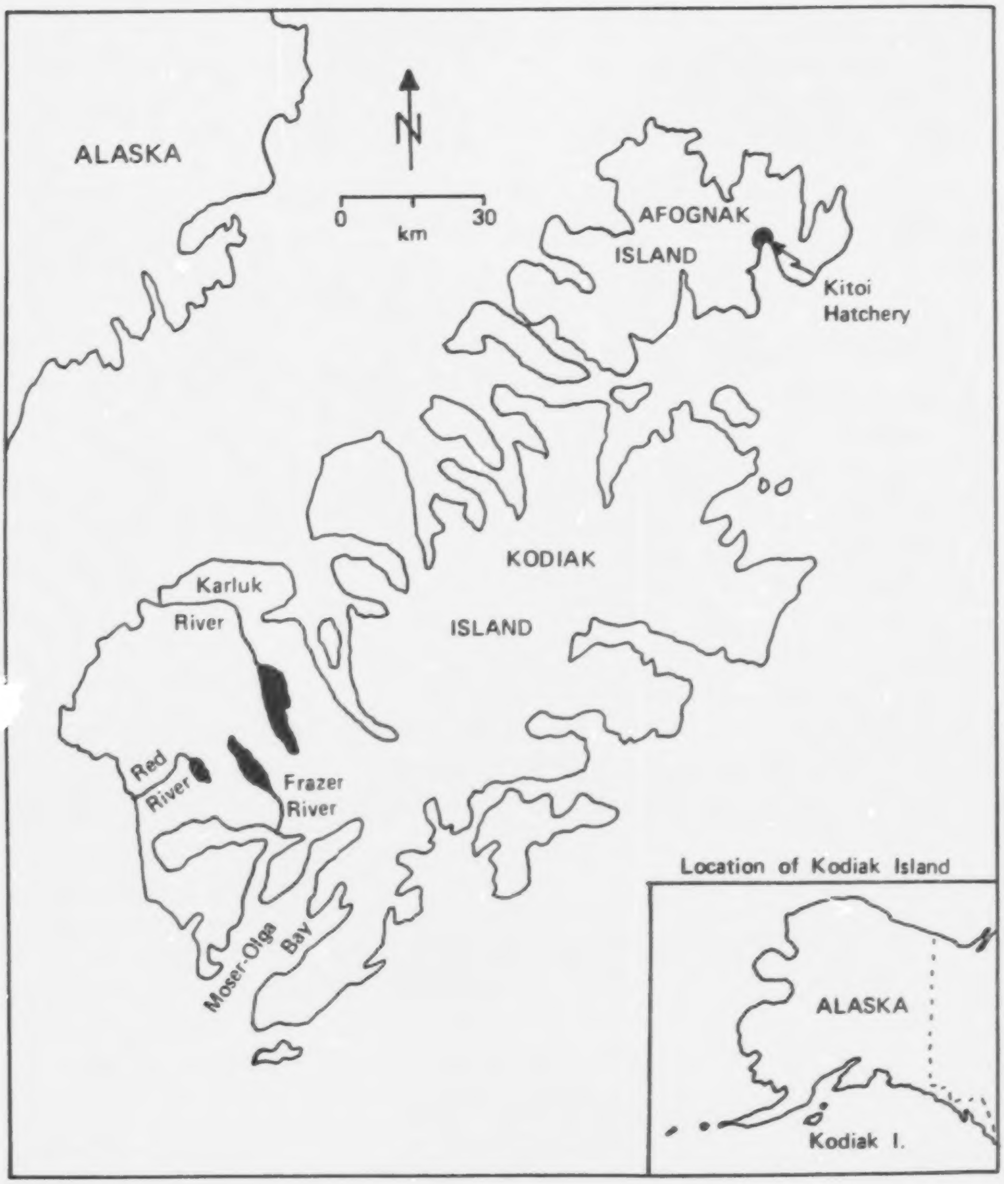
Chinook escapement is monitored annually at the Frazer Lake fishpass.

Table 14. Comparison of techniques used in chinook transplants to Great Lakes during 1873 to 1970.[a]

Period	No. Years	Total No. Released in Great Lakes	No. Release Groups	Mean No. per Release Group	Mean No. per Year	% Released at Different Life Stages				Transplant Success
						Egg	Fry	Fingerling[b]	Smolt	
1873-1898	26	8,794,000	237	37,000	338,000	0	99	1	0	No
1919-1933	15	2,417,000	40	60,000	161,000	0	89	11	0	No
1967-1970	4	5,916,000	34	174,000	1,479,000	0	0	0	100	Yes

[a] Extracted from Parsons (1973).

[b] Fingerlings were usually less than 1-yr-old, but some were older.


ALASKA
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Frazer
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Bay
Location of Kodiak Island
ALASKA
Kodiak I.

Fig. 10. Kodiak Island showing location of Frazer, Red and Karluk lake systems (from Blackett 1979).

Table 15. Chinook salmon introductions and returns to the Frazer Lake fishpass, 1966-1985.[a, b]

Year	Fry Releases	ADULT RETURNS FROM Released Fry	ADULT RETURNS FROM Natural Spawning
1966	42,000	0	0
1967	56,000	0	0
1968	46,000	0	0
1969	16,000	0	0
1970	0	2	0
1971	0	24	0
1972	0	113	0
1973	0	35	0
1974	0	12	0
1975	0	0	7
1976	0	0	28
1977	0	0	208
1978	0	0	131
1979	0	0	53
1980	0	0	66
1981	0	0	22
1982	0	0	48
1983	0	0	86
1984	0	0	85
1985	0	0	165
Total	160,000	186	899

[a] Data for 1966-1978 from Blackett (1979); data for 1979-1985 from R. Blackett (pers. comm.).

[b] Additional chinook spawn in the Frazer and Dog salmon rivers below the fishpass, but only fish ascending the fishpass are counted.

Suggested reasons for apparent transplant success

Donor/recipient combination

The Frazer River was a good candidate for colonization with chinook for several reasons. Preliminary studies indicated that it had good spawning and rearing potential, and the impassable falls at the Frazer Lake outlet appeared to be the only reason for the barren state of this system. The nearby Red and Karluk Rivers were similar physically and environmentally to Frazer River, including comparable length of freshwater migration routes, and could provide suitable broodstock. The Karluk River which served as the donor system is located approximately 150 km from the Frazer River. Note that the direction of entry from the sea is opposite for the two systems (Fig. 10).

Transplant strategy

Moderate fry plants approximating 40,000 juveniles each year over a 4-yr period succeeded in establishing a small, self-sustaining run. A fishway constructed at the Frazer River falls in 1962 allowed upstream access to returning spawners.

APPENDIX 7. CHINOOK TRANSPLANTS IN ALASKA

Sources of information: SSRAA 1982; K. Johnson (pers. comm.)

Synopsis

In Alaska, the salmon transplant strategy is geared for genetic diversity, protection of wild stocks and maximum utilization of natural resources. The donor stocks must be healthy, local and with a strong escapement record. Initially, the transplant operation is carefully monitored for desired characteristics in the returning adults, such as adult migration timing, age structure and fish quality in the terminal fishery. If these are favourable, a hatchery is constructed at the new site for intensive propagation of the introduced population. Chinook juveniles are artifically reared for 1 yr and released in May and June at 30 g.

Background

The current transplant techniques being developed for chinook, chum and coho salmon by the Southern Southeast Regional Aquaculture Association (SSRAA) in Alaska are aimed at rebuilding the existing populations and establishing new runs. The research deals with developing a strategy for transporting stocks within an area while ensuring protection of existing stocks, maintaining adequate genetic diversity and maximizing the use of resources available for production.

Transplant strategy

Two main approaches are taken for developing new chinook populations for production purposes. First, an appropriate broodstock population is developed at the new site by introducing selected donor stocks over several years and monitoring the new population for desired characteristics such as adult migration timing, age structure and fish quality in the terminal fishery. The donor stock must be healthy, have a good escapement record to allow for long-term, large-scale egg-takes, and must come from within an 80-180 km radius of the recipient site in order to minimize genetic problems. Second, if the introduced population has the desired characteristics, capital is invested to expand this stock by constructing hatchery facilities on site for intensive, annual propagation of that stock. Artificial propagation of the introduced stock ensures high freshwater survival and large juvenile releases, and is particularly important in areas with limited spawning and rearing habitat. Initial freshwater rearing is followed by saltwater pen rearing for the final 3-7 wk. Reared chinook are released in May to June as 30 g yearlings.

Transplant returns

The chinook colonization programs in Alaska are still in initial stages and complete program evaluation is not available. To date, ocean survivals of up to 6% have been observed.

Project assessment

The transplant program is carefully monitored, especially in the initial stages. Tagging studies are conducted annually by the SSRAA to determine marine survival, catch locations, return timing and contribution to commercial fisheries. The findings are used to assist in planning of future releases.

Suggested reasons for expected transplant success

It is still too early to fully evaluate the chinook transplant programs in Alaska. However, the initial evidence of success may be attributed largely to the selection of appropriate donor stocks and to the rearing strategy.

Donor stock

The donor stock must be healthy, local (within 80-180 km radius) and with a strong escapement.

Rearing strategy

Large size at release is probably one of the key factors leading to successful adult returns. Chinook are reared for one year and released in May and June at about 30 g. Such releases have resulted in an ocean survival of 6% at Neets Bay, Alaska. Despite the large size at release, no significant increase in the proportion of jacks was observed (K. Johnson, pers. comm.).

APPENDIX 8. CHINOOK TRANSPLANTS IN WIND RIVER, WASHINGTON

Source of information: Wahle and Chaney 1981.

Synopsis

A successful, largely hatchery-propagated run of spring chinook has been developed in the previously barren Wind River in the Columbia basin. The donor stock consisted of chinook captured at Bonneville Dam on the Columbia River mainstem and represented a heterogenous population of upriver-bound stocks. During the 9 yr of active adult transplants between 1955 and 1963, about 500 fish were transported annually from the Bonneville Dam to the Carson hatchery on Wind River for a total of 4,239 adults. During that period, approximately 13.8 million chinook eggs were taken producing about 10.6 million yearlings for a juvenile release of about 1 million per year. Adult transfers from Bonneville Dam were discontinued after 1963. Thereafter, some 0.2-3 million hatchery smolts were released annually using broodstock consisting entirely of hatchery returns to the Wind River.

Presently, annual adult escapements to the Carson hatchery average around 3,000 chinook. This production is augmented by natural spawning above and below the hatchery. The successfully transplanted chinook in the Wind River contribute significantly to the regional commercial and sport fisheries.

Background

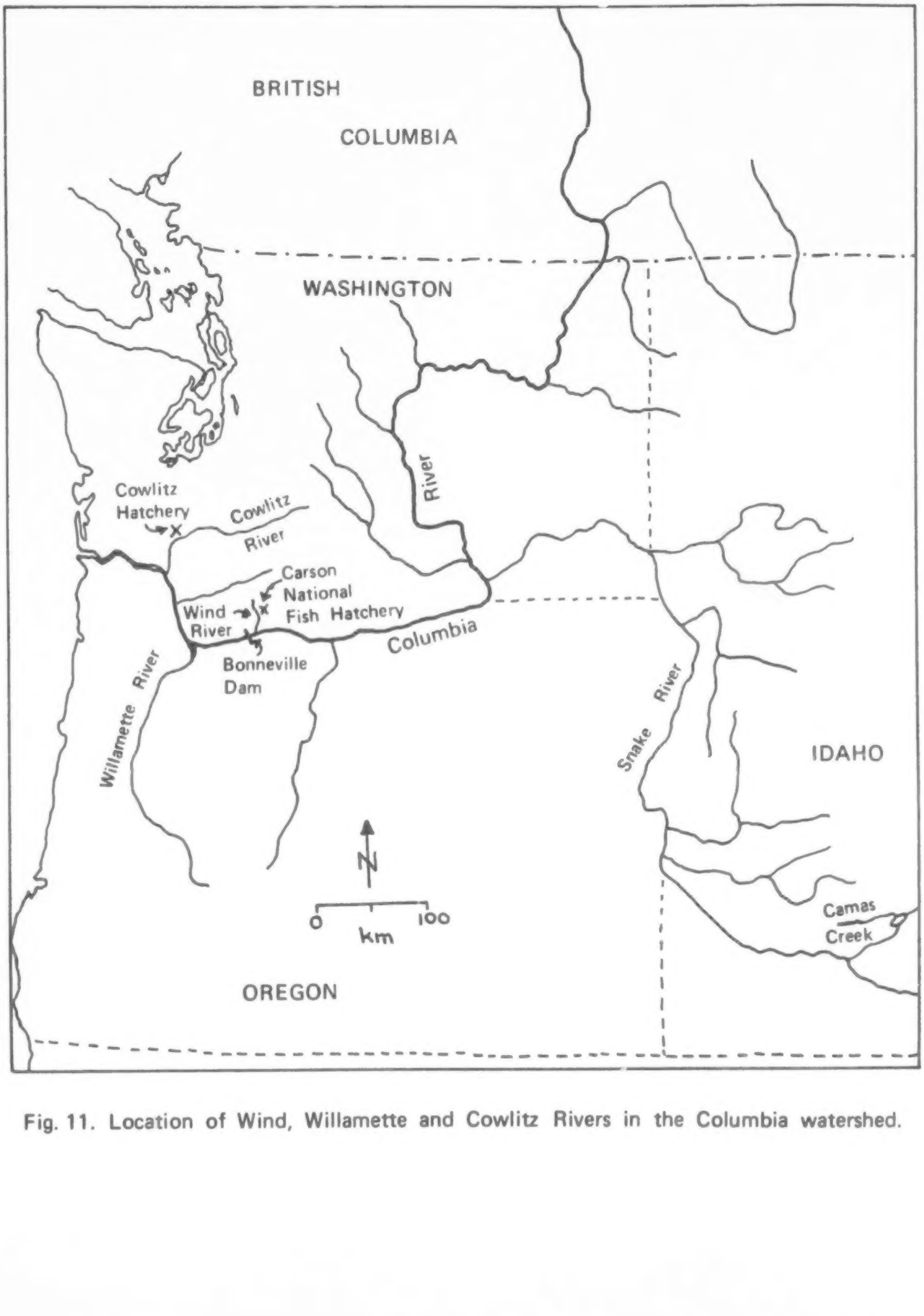
Historically, the Wind River was barren of salmonids due to the impassable Shipperd Falls located some 6 km above the confluence with the Columbia River mainstem (Figs. 11 and 12). The upper Wind River drainage was believed to contain substantial chinook spawning and rearing areas capable of supporting an introduced stock. Consequently, transplant programs were initiated in the 1930s to develop a spring chinook run that would contribute to commercial and sport fisheries.

Early transplants between 1938 and 1953 failed to produce any returns. During that period, approximately 300,000 chinook juveniles originating from the lower Willamette River (Fig. 11) were reared and released at the new site. Since the Willamette River is located downstream of Wind River, it is possible that the returns from this transplant failed to migrate upstream past the parental river. A further release in 1946 of 20,500 chinook fingerlings (age 1+) originating from the Camas River donor stock in Idaho (Fig. 11) produced the first adult returns to the Wind River and gave some evidence of success when transplanting an upriver chinook stock to a downstream site. With this in mind, the intensive 9-yr long adult transplant program was implemented in the Wind River watershed in 1955.

Transplant strategy

In 1945, the Carson National Fish Hatchery was built on the upper Wind River, 32 km above the falls (Fig. 12), to provide large annual releases of reared juveniles, as well as to extend the imprinting period. In 1956, a fishway was constructed at the impassable Shipperd Falls allowing the natural use of the available spawning and rearing habitat by any transplant returns. Adults captured at the Bonneville Dam were transported to the Carson hatchery on the upper Wind River and held there for 5-6 mo until maturation in August or September. Eggs were incubated and juveniles reared for about 13 mo prior to release in the Wind River in late March to early May.

The numbers of adults and juveniles involved in the Wind River transplant program are shown in Table 16. During the 9 yr of active adult transplants between 1955 and 1963, about 500 chinook were moved annually from Bonneville Dam to the Carson hatchery on Wind River for a total of 4,239 adults. During that period, approximately 13.8 million chinook eggs were taken (8.5 million from the donor stock and 5.3 million from hatchery returns to Wind River) resulting in an overall release of about 10.6 million yearlings, or about 1 million each year. After 1963, the broodstock consisted exclusively of hatchery returns to the Wind River and some 0.2-3 million hatchery releases were made annually.


BRITISH
COLUMBIA
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Carson
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Columbia
River
Willamette River
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IDAHO
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Fig. 11. Location of Wind, Willamette and Cowlitz Rivers in the Columbia watershed.

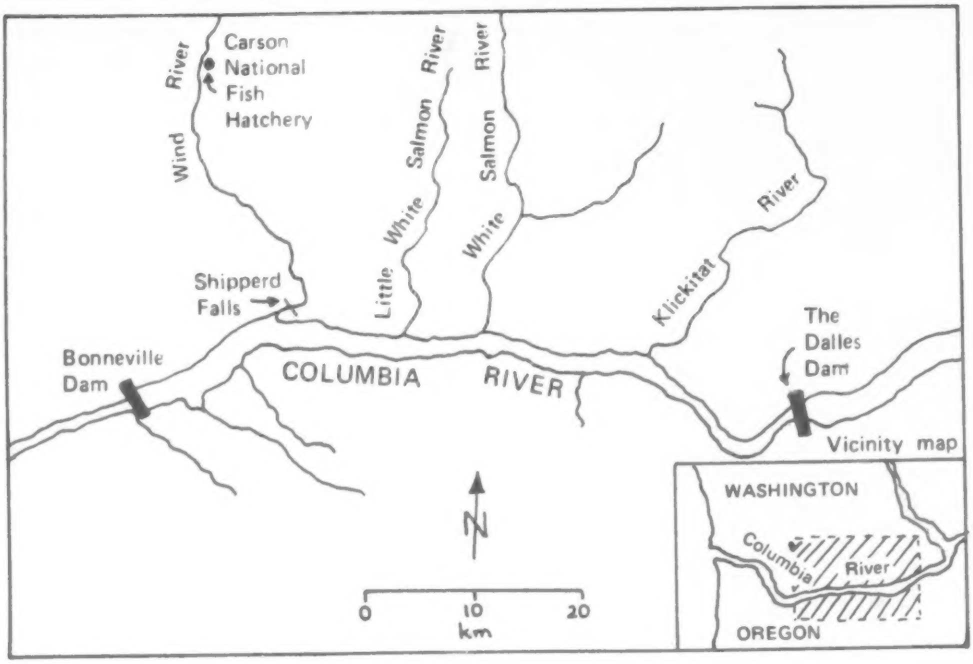
Carson
National
Fish
Hatchery
Wind River
Little White Salmon River
White Salmon River
Klickitat River
Shipperd
Falls
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Fig. 12. Wind River and the surrounding area (from Wahle and Chaney 1981).

Table 16. Wind River chinook transplantation program, 1955-1979.[a]

Year	No. Adults Hauled	Shipperd Falls Adult Count	Carson Hatchery Returns[b]	No. Fingerlings Released at Hatchery	Brood Year
1955	517	N/A	-	-	-
1956	498	10	-	-	-
1957	426	1	-	967,000	1955
1958	524	26	-	623,000	1956
1959	184	N/A	107	733,000	1957
1960	527	854	552	1,016,000	1958
1961	545	1,032	609	261,000	1959
1962	479	2,515	1,718	1,479,000[c]	1960
1963	513	1,255	825	1,265,000	1961
Total	4,239				
1964	-	5,429	2,517	3,037,000	1962
1964	-	-	-	39,000	1963[d]
1965	-	2,284	1,474	1,154,000[e]	1963
1966	-	4,174	3,666	1,909,000	1964
1967	-	(Counts	2,749	2,412,000	1965
1968	-	discontinued)	663[f]	1,613,000	1966
1969	-		1,609	1,535,000	1967
1970	-		3,120	757,000	1968
1971	-		4,250	1,178,000	1969
1972	-		6,641	1,409,000	1970
1973	-		2,189	1,541,000	1971
1974	-		1,563	2,001,000	1972
1975	-		4,905	2,000,000	1973
1975	-		-	197,000	1974[d]
1976	-		5,496	2,291,000	1974
1976	-		-	253,000	1975[d]
1977	-		2,975	2,813,000	1975
1978	-		2,976	2,836,000	1976
1979	-		2,541	1,792,000	1977

[a] Source adapted from Wahle and Chaney (1981).

[b] After a sufficient number of adults entered the hatchery, entrance to the hatchery was often blocked, forcing surplus adults to spawn in the Wind River and its tributaries.

[c] First year released juveniles included progeny of non-transplanted adults.

[d] Time of release study.

[e] Included last juveniles from transplanted fish.

[f] Last year of possible returns resulting from first generation progeny of tranplanted fish.

Transplant returns

Adult returns to the Carson hatchery on Wind River increased from around 100 in 1959 to a maximum of 6,600 in 1972 and averaged around 3,600 during the 1970s (Table 16). Additional chinook spawn naturally each year above and below the Carson hatchery.

Project assessment

The evaluation program of the Wind River chinook transplant included adult counts at Shipperd Falls fishway (counts were discontinued in 1967), adult returns to Carson hatchery on Wind River, juvenile releases from Carson hatchery, spawning ground surveys for adults and redds, mark-recovery programs and creel census to determine contribution to fishery catches, and inventory of surplus eggs and juveniles available from Carson hatchery for transplants into other areas.

Mark recovery programs showed that the Wind River spring chinook contribute to the freshwater sport fishery and to marine commercial and recreational fisheries from Alaska to California, as well as to the mainstem Columbia River fisheries. The success of this transplant is further demonstrated by the transfer between 1960 and 1979 of approximately 50 million eggs and juveniles from the Carson hatchery to other Pacific Northwest locations.

Suggested reasons for transplant success

Donor/recipient combination

Although barren of salmon prior to introductions, Wind River had a natural spawning and rearing habitat and could potentially support an introduced chinook run. A physical barrier in the form of impassable falls was the only apparent reason for the historical absence of salmon in that system.

The donor broodstock consisted of heterogenous, upstream-bound chinook populations captured at Bonneville Dam, 15 km downstream from the Wind River confluence with the Columbia River mainstem (Fig. 11). It therefore represented a heterogenous population of upriver stocks from the same watershed. The wide gene pool probably facilitated the process of natural selection for the best-suited individuals to the new environment. Also, the transplanted adults were capable of migrating to the recipient stream, since it is located below the parental streams.

Transplant strategy

Early construction of a hatchery (1945) on the recipient stream provided a suitable facility for the artificial propagation of the introduced stock, while the early construction of a fishway in 1956 assured spawner access to the historically blocked Wind River.

The broodstock was developed during an intensive and prolonged adult transplant program extending over 9 consecutive years and involving about 500 adults each year. Transported adults were successfully held at the hatchery for up to 6 mo until maturation, and chinook juveniles were reared for 13 mo prior to release. The large annual releases and the extended imprinting period were aimed at increasing adult returns and enhancing the homing accuracy to the recipient site. After 1963, only the returns to the Wind River hatchery were used for broodstock. This approach hastened the process of natural selection for the best-adapted individuals to the new environment.

APPENDIX 9. CHINOOK TRANSPLANTS IN WILLAMETTE RIVER, OREGON

Sources of information: Hansen 1976, 1977, 1978; Hansen and Williams 1979; Howell et al. 1985a; L. Korn (pers. comm.); R. Williams (pers. comm.).

Synopsis

A partially hatchery-sustained run of fall chinook has been developed in the Willamette River in the Columbia River basin through annual releases during the 1970s of over 10 million 5-7 g chinook juveniles. The transplant program involved two donor groups, the early - spawning Tule stock and the later-spawning Cowlitz River stock, both from the Columbia River basin. The transplanted Tule stock has become a partially self-sustaining population; the transplanted Cowlitz stock failed to develop a natural run and must be entirely hatchery-sustained.

The success of the Willamette River fall chinook transplant using the Tule stock is attributed primarily to the selection of a nearby, upriver, genetically pliable and abundant hatchery-produced stock; the semi-natural, on-site pond rearing technique; and the annual massive outplantings of juveniles.

Background

Historically, the Willamette River in the Columbia River basin (Fig. 11) supported spring chinook but no fall chinook run. The latter apparently could not become established due to a 15 m high falls located in the lower reaches of the Willamette River. At low autumn water levels, these falls formed a severe barrier to the upriver migrants. In the 1970s, a modern fishway was built at the falls and efforts began to colonize the river with fall chinook. The aim of the transplant was to develop a self-propagating natural run of fall chinook to support commercial and sport fisheries.

Transplant strategy

Two donor stocks were selected from the Columbia River basin: the early-spawning (September-October) Tule chinook which provided the majority of the broodstock and the late-spawning (October-November) Cowlitz River chinook (Fig. 11). The Tule fish are a blend of hatchery chinook which have been used widely and successfuly over many years for artificial propagation of fall chinook in the lower Columbia River where they also spawn naturally. The Cowlitz hatchery chinook were chosen for their proximity to the recipient site, adaptability to hatchery rearing, and especially for their late spawning timing. These fish are well suited for developing a river sport fishery since they enter the streams in September as bright, mature fish and spawn several months later. By contrast, the Tule fish enter the river as ripe adults and are best suited for offshore commercial fishery.

Egg collection and incubation to fry stage of Tule and Cowlitz chinook were conducted at the Bonneville and Cowlitz hatcheries respectively. The Cowlitz fry were reared entirely in the hatchery to 3-4 g and scatter-released in May and June in the Willamette system (Table 17). In contrast, emergent Tule fry were transported to the lower Willamette River Valley and reared for approximately 4 mo starting in December, in a 50,000 m^2gravel pond adjacent to one of the major recipient tributaries. Sub-yearlings were trucked from the pond during March to June at about 5-7 g (Table 17) and released without holding at various sites along the Willamette River system. Fry trapping data indicated that the released juveniles migrated the 100 km to the sea within about 4-6 wk after release, which allowed additional freshwater rearing and imprinting. Annual massive stocking of the Willamette River with Tule juveniles has been conducted since the late 1960s with approximately 5-10 million fish released each year (Table 17). Experimental releases of the Cowlitz fall chinook were made from 1972 to 1978 and were subsequently discontinued due to poor returns.

Transplant returns

The Willamette River currently supports wild and hatchery runs of the Tule fall chinook (Table 17). Escapements monitored at the Willamette falls have increased from around 1,000 in 1966 to 34,000 in 1974 but declined somewhat in later years. The Tule hatchery fish comprised between 5-77% of the adult returns during 1979 to 1984 (Table 17). The remainder consisted of a natural spawning run developed from the transplants. Smolt-to-adult survival (catch and escapement) for the 1978 and 1979 broods was 0.97% and 0.91% respectively which was higher than the Bonneville hatchery survival of 0.39% and 0.14% for the same respective broods.

The successful Tule transplant will continue to be supplemented with annual releases of reared juveniles. This should increase the natural salmon production in the presently underutilized Willamette River system and produce a larger spawning population than would be expected given continued fishing pressure and the absence of hatchery aid. Compared to the above Tule transplant, the Cowlitz transplant has shown few returns and little colonization success.

Project assessment

The escapements of fall chinook to the Willamette system have been monitored annually at the Willamette falls since 1965. Starting in 1969, aerial surveys of the Willamette River system have been conducted to determine the presence and distribution of redds from naturally-spawning fall chinook.The returns of pond-reared releases to the Willamette River were excellent and represent the highest survival of any hatchery-produced fall chinook in the Columbia watershed. However, accurate evaluation of the chinook transplants into the Willamette system is not possible since the natural and hatchery returns are not differentiated. Recently, however, portions of hatchery juveniles from the 1978 to 1982 broods were differentially marked. The return data should clarify the relative survival of wild and hatchery chinook, and the effectiveness of pond-rearing in the Willamette Valley. In 1977, a seining study was initiated in the Willamette system to determine the life history of chinook juveniles originating from the transplants. The findings should help develop an optimal rearing and release strategy.

Table 17. Numbers and sizes of fall chinook juveniles released into the Willamette River system (1967-84 broods) and calculated escapement of fall chinook adults and jacks over Willamette Falls, 1955-1960 and 1965-1984.[a]

	TULE STOCK			COWLITZ STOCK				
Year	Number Released (Millions)	Size at Release (g)	Time of Release	Number Released (Millions)	Size at Release (g)	Time of Release	Escapement[b]	% Hatchery Fish
1955							75	
1956							21	
1957							53	
1958							125	
1959							16	
1960							9	
1965							79	
1966							1,026	
1967							2,012	
1968	1.741	5.4		0			4,246	
1969	1.341	4.6		0			6,957	
1970	10.710	5.9		0			7,558	
1971	10.566	7.2		0			5,090	
1972	11.037	5.2		2.315	3.3	Jun	11,826	
1973	11.646	6.3		0.496	4.0	May	22,237	
1974	11.896	5.7		2.497	4.0	May	34,189	
1975	5.544	6.0		0	-	-	33,772	
1976	6.007	5.7		2.303	3.7	May	30,200	
1977	10.889	5.1		0	-	-	26,124	
1978	0.301[c]	-		0.151[c]	19.7	Nov	17,902	
1979	4.692	6.8	May	0			10,341	51[d]
1980	6.349	5.2	Mar - Jun	0			8,385	5[d]
1981	5.903	6.1	Apr - Jun	0			17,775	48
1982	6.751	5.2	Apr - May	0			26,883	69
1983	6.911	5.8	Apr - May	0			13,733	77
1984	5.171	-		0			21,144	67
1985	4.534	-		0			-	-
10-year mean (1974-1983)							21,930	

[a] Data extracted from Hansen (1977), Hansen and Williams (1979) and Howell et al. (1985a).
[b] Primarily hatchery and wild returns of "Tule" stock.
[c] Experimental, marked releases.
[d] Age 3 fish only.

Suggested reasons for transplant success

Donor/recipient combination

The Willamette River historically supported a spring chinook run and therefore could potentially support a fall chinook population when the Willamette Falls barrier, which became an obstacle to ascending salmon in the fall months, was removed. Also, being part of the Columbia River watershed, the Willamette River could be readily supplied with local donor stocks.

The Tule donor stock was an excellent candidate for the Willamette River transplant. Tule fish are a proven and well-established hatchery population which originated from broodstock captured at Bonneville Dam, and represented a mixture of upriver races from the same watershed relative to the Willamette system. Since the Tule fish contain a diverse gene pool they are likely more genetically pliable than a single river stock. This probably facilitated the establishment of a self-propagating run in the Willamette River. The Tule stock was also capable of providing large quantities of eggs for long-term transplants. In addition, compared to many other Oregon stocks, the Tule fish migrate earlier and enter the stream in a ripe condition, so that immediate egg-take is possible without adult holding. Finally, the Tule stock is known to benefit the Oregon commercial fisheries.

Transplant strategy

Construction of a fishway over the Willamette Falls in the 1970s allowed the upriver passage of returning transplant progeny and facilitated the establishment of a natural spawning run. Large annual plantings of about 5-10 million juveniles reared to 5-7 g favoured high returns. Semi-natural pond rearing of the Tule juveniles in the receiving watershed provided for extended imprinting, some natural food, reduced crowding, and generally more natural rearing conditions compared to hatchery rearing. This probably resulted in fitter juveniles and increased marine survival. The relatively early egg-takes using the early migrating Tule stock allowed for earlier incubation and ponding, and subsequent earlier fry outmigration, generally by May. This allowed the fry to bypass the unfavourable, man-induced summer conditions of low water flows, warmer temperatures and higher pollutant levels in the Columbia River.

Weaknesses of the transplant program

Compared to the successful Tule transplant, the Cowlitz donor stock has failed to produce significant returns or establish a self-sustaining run in the Willamette system. Possible reasons include the production of smaller, inferior, entirely hatchery-reared Cowlitz juveniles compared to the larger semi-naturally pond-reared Tule juveniles. Another factor may be the poor quality of release sites for Cowlitz fish compared to Tule fish, and later release timing which resulted in a summer migration down the Columbia River when the water quality is lower (mainly due to higher temperatures).

Recommendations (L. Korn, pers. comm.)

1. Ideally, the broodstock should consist of adults returning to the Willamette River ponds since their progeny will probably be more successful

than the donor fish in utilizing the natural spawning and rearing areas in the new area. At present, due to shortage of funds, Bonneville hatchery adults are still utilized as broodstock for the Willamette River.

2. Acclimation ponds should be built at release sites along the Willamette River to increase juvenile survival. Presently, juveniles are trucked from the main pond and released directly into the river.

3. Once the best-suited donor stock is selected and transplants initiated, the progeny of successful returns should be further studied for ocean and freshwater fishery contributions in order to confirm the suitability of that stock and develop appropriate fishery management strategies. The life history pattern of the transplanted stock should also be studied in order to determine optimal fish culture strategies such as time and size at release.

APPENDIX 10. CHINOOK TRANSPLANTS IN LAKE COEUR D'ALENE, IDAHO

Source of information: LaBolle MS 1985.

Synopsis

Between 1982 and 1985, non-indigenous fall chinook juveniles were introduced into Lake Coeur d'Alene in Idaho to control the expanded kokanee population. To-date, this transplant has shown considerable success and resulted in some natural spawning and a popular sport fishery. However, the program is still in its initial stages and requires adjustment of the stocking rate and of the size and timing of chinook releases.

Background

Lake Coeur d'Alene is located in the Idaho Panhandle and is drained by the Spokane River which enters the Columbia River system (Fig. 13). A hydroelectric facility at Post Falls, some 13 km below the lake outlet, has regulated the lake's water level since 1903. Between 1937 and the late 1950s, Lake Coeur d'Alene was stocked annually with kokanee fry. By the mid-1970s, these plantings had developed into a self-sustaining population with commercial and sport fishery harvests exceeding 500,000 fish. This fishery improved dramatically when the earlier stocking rate of a few thousand fry was increased to 1 million fry. By 1980, the kokanee population exceeded the natural capacity of the lake and the resulting small-sized adults no longer attracted the anglers. Therefore, the introduction of a fish predator in the form of landlocked fall chinook was proposed in order to control kokanee abundance and provide a limited trophy fishery.

Transplant strategy

Annual chinook releases into Lake Coeur d'Alene are shown in Table 18. Between 1982 and 1985, 11,000-60,000 chinook juveniles were released each year into the lake. The initial egg source came from the downstream Bonneville stock in the Columbia River. After 1984, eggs originated from the landlocked Lake Michigan chinook. Chinook eggs were incubated and the juveniles reared for 9-10 mo at Hagerman and Mackay facilities in southern Idaho (Fig. 13). Fish were released in July, August and October at 10-48 g (Table 18).

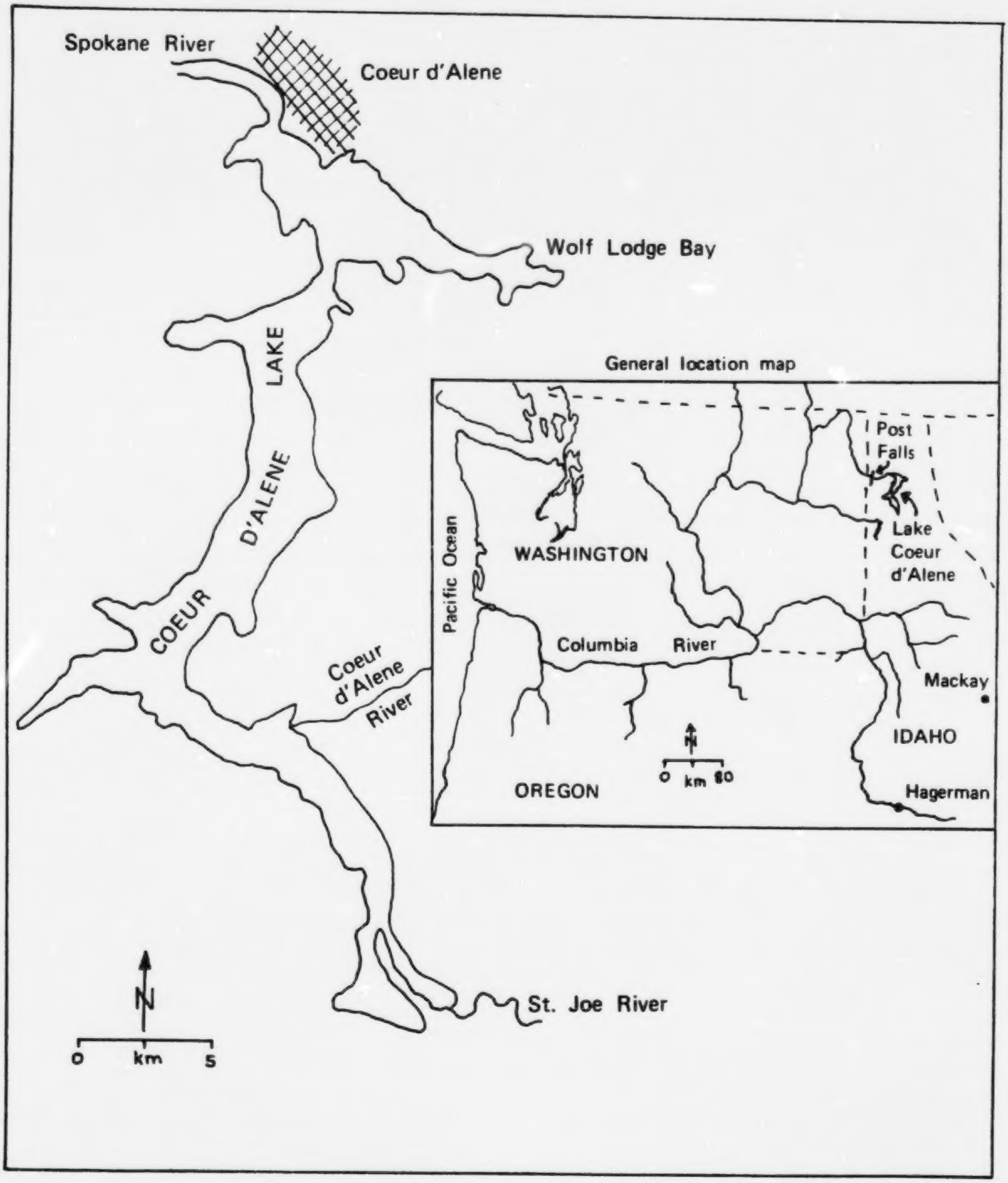
Spokane River
Coeur d'Alene
Wolf Lodge Bay
COEUR D'ALENE LAKE
Coeur d'Alene River
St. Joe River
N
0 km 5
General location map
Post Falls
Lake Coeur d'Alene
WASHINGTON
Pacific Ocean
Columbia River
Mackay
IDAHO
Hagerman
OREGON
N
0 km 80

Fig. 13. Location of Coeur d'Alene Lake in Idaho.

Table 18. The number and size of fall chinook salmon released into Coeur d'Alene Lake, Idaho, 1982-1985.[a]

Release Date	No. Released	Mean Weight (g)	Mean Length (mm)	Donor Stock
Jul 19, 1982	28,700	26.7	137	Bonneville
Oct 5, 1982	5,700	47.7	150	Bonneville
Total 1982	34,400			
Aug 9, 1983	30,100	9.6	109	Bonneville
Oct 26, 1983	30,000	21.2		
Total 1983	60,100			
Oct 19, 1984	10,500	35.4	150	Lake Michigan
Total 1984	10,500			
Oct 16, 1985	11,100	36.8	136	Lake Michigan
Oct 17, 1985	7,400	36.8	143	Lake Michigan
Total 1985	18,500			

[a] Extracted from LaBolle (MS 1985).

Transplant returns

The initial release of juveniles in 1982 resulted in a small run of about 20 jack chinook observed in the lake tributary in the fall of 1983. In 1984, a successful sport fishery occurred in the lake on 3-yr-old chinook weighing up to 12 kg, and in 1985, several hundred mature fish entered and spawned in Wolf Lodge Creek, a tributary to Lake Coeur d'Alene. In contrast, survival of fish from the 1983 release was apparently poor as indicated by the low catch and escapement. This may be due to the late October release that year of relatively small (21 g) juveniles (Table 18) which could not feed on the large kokanee fry.

Suggested reasons for transplant success

Donor stock

Chinook species were selected for introduction into Lake Coeur d'Alene since they were thought to have the "greatest predatory inertia" of the salmonid predators considered. That is, the period from juvenile release to maximum predatory impact is relatively short. Also, the fall chinook require only 9-10 mo of hatchery residence to reach the post-smolt stage when they no longer have the "urge" to migrate seaward but rather tend to residualize in fresh water; in comparison, spring and summer chinook require a longer period to reach this post-smolt stage. The initial donor fish came from the Bonneville stock, also known as the Tule stock, which is a successful hatchery population widely used for propagation of fall chinook in the lower reaches of the Columbia River watershed.

Transplant strategy

The release of post-smolts resulted in a resident chinook population in the Lake Coeur d'Alene system, where the absence of a marine phase reduced straying and eliminated marine-related mortality. The kokanee population provided abundant prey for the introduced non-indigenous chinook. Suitable time and size at release of chinook juveniles was a key requirement for the success of this transplant program aimed at kokanee control; small chinook released late in the fall were unable to consume age 0 kokanee, which double in size through the summer, and thus had poor survival.

APPENDIX 11. CHINOOK TRANSPLANTS IN LAKE SAKAKAWEA, NORTH DAKOTA

Sources of information: Anon. 1985a; Berard and Power 1985.

Synopsis

A successful recreational chinook fishery has developed in Lake Sakakawea, a Missouri River reservoir, since the first juvenile outplanting in 1976. The introduced population originated largely from chinook stocks in Washington and Michigan and is entirely hatchery-sustained through annual transplants of chinook eggs from the Great Lakes and the release of up to 27 g hatchery-reared juveniles. Success of this artifically-propagated, landlocked chinook transplant is attributed mainly to the large release size and large annual outplants of juveniles, and to the abundance of forage species in the reservoir.

Background

Lake Sakakawea is a large Missouri River reservoir located in North Dakota (Fig. 14). Attempts were made in the late 1960s to establish a salmon fishery in the reservoir by colonizing it with coho salmon. However, this attempt showed limited success since coho grew slowly due to lack of adequate forage species. In 1971, rainbow smelt were introduced from the Great Lakes and within a few years these developed into a strong forage base in the reservoir. Trial introductions of chinook salmon in the mid-and late 1970s (Table 19) showed these to be a better choice than the slower-growing coho. Consequently, the coho stocking program was discontinued in 1982 in favour of large plantings of chinook juveniles.

Transplant strategy

The source and number of chinook broodstock transplanted into Lake Sakakawea are shown in Table 19. Eyed and green eggs were supplied primarily by chinook stocks from the State of Washington (1975, 1976, and 1977 broods) and Michigan (after 1981). Michigan eggs came from the Great Lakes chinook which originated from the Pacific stocks. The Great Lakes chinook had to be used for the Lake Sakakawea transplants since disease-free eggs were not available from the West Coast.

Eggs were hatched and fry were reared at the Garrison Dam National Fish Hatchery located at the southeast end of Lake Sakakawea (Fig. 14). Juveniles were released August-September at a mean size of 3-27 g (Table 19). Fish were planted in the southeastern portion of the lake where numerous bays provide deep, cool, clear water. All chinook juveniles stocked since 1981 were chemically imprinted with morpholine during smoltification. Since 1976, up to 1.1 million chinook juveniles have been released annually into Lake Sakakawea.

Adult returns

The 1976-78 chinook introductions produced first spawning runs in 1979-81 indicating transplant success. Stocked chinook had a very high survival approaching 70%, and up to 10 kg adults were captured. Growth rates compare favourably with other established inland freshwater chinook populations, such as those in Lakes Superior and Michigan. Currently Lake Sakakawea supports a healthy recreational fishery on the landlocked chinook.

Project assessment

Biological studies conducted on Lake Sakakawea include monitoring of fish abundance, distribution and growth rates. Based on the results, recommendations are being developed for future stocking programs.

Suggested reasons for transplant success

Transplant strategy

The introduced rainbow smelt provided an abundant, high quality food supply for the transplanted piscivorous chinook. Large outplantings of up to 1 million hatchery juveniles each year, and the large size of up to 27 g at release favoured good adult production. Since the introduced chinook population is entirely landlocked, no losses were incurred from marine predation and straying.

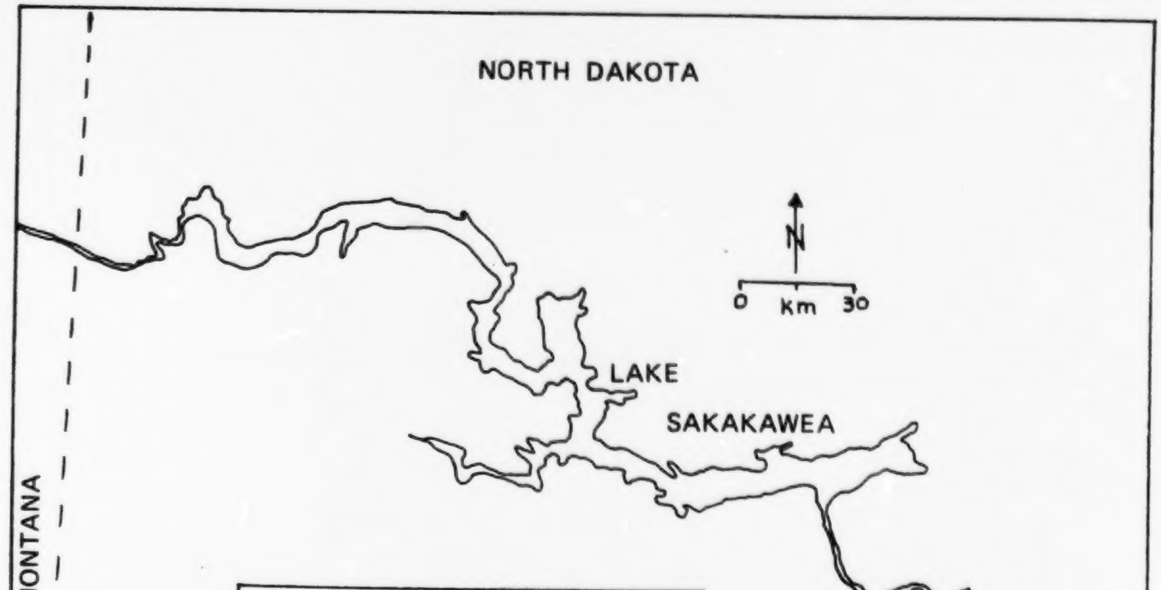
NORTH DAKOTA
MONTANA
SOUTH DAKOTA
LAKE
SAKAKAWEA
N
0 km 30
Missouri
River
flow
Lake
Oahe
CANADA
North Dakota
Great Lakes
Washington
Michigan
UNITED STATES
0 km 3000
General location of North Dakota, Michigan and Washington states, and of Great Lakes

Fig. 14. Location of Lake Sakakawea in North Dakota.

Table 19. Source and number of chinook salmon broodstock transplanted to Lake Sakakawea, 1975-1983 broods (from Garrison National Fish hatchery personnel).[a]

Year of Egg-Take	Egg Source	No. Eggs Received	Eyed (E) or Green (G)	No. Stocked	Size at Stocking L (cm)	Size at Stocking Wt. (g)
1975	Abernathy, Wash.	N/A	E	41,500	10.8	10.5
1976	Spring Creek, Wash.	229,270	E	184,000	8.3	4.8
1977	Spring Creek, Wash.	372,000	E	334,000	8.4	4.8
1980	Lake Sakakawea	89,892	G	18,635	14.7	26.7
1980	Michigan	699,500	G	43,650	12.2	15.1
1981	Private hatchery, Oregon	225,000	E	173,370	7.5	3.3
1981	Genoa, Wisc.	198,000	G	98,854	7.4	3.3
1981	Lake Sakakawea	416,655	G	124,584	9.9	8.0
1982	Michigan	1,888,110	G	1,139,260	8.0	4.2
1983	Michigan	2,293,200	G	823,610	9.0	5.7

[a] From Berard and Power (1985).

APPENDIX 12. CHINOOK TRANSPLANTS IN NEW ZEALAND

Sources of information: Commission of Fish and Fisheries 1903; Ayson 1910; Anon. 1983; McDowall 1985; Todd 1985; Unwin MS 1985; G. Glova (pers. comm.).

Synopsis

The South Island in New Zealand is the only place in the southern hemisphere where chinook salmon from North America have become firmly established. Between 1901 and 1907, approximately 1.7 million chinook juveniles, imported as eggs from California, were planted in the Waitaki River system in the South Island of New Zealand. Since that time, chinook have become abundant in rivers along most of the east coast of the South Island where they are a popular angling species.

The success of chinook transplants in New Zealand is attributed to several factors. These include a suitable receiving stream with good potential habitat for natural chinook production and a simple and relatively short (less than 25 km) migration route to the sea; a suitable donor stock taken from the same latitude as the receiving site; a relatively intensive planting effort over several successive years, followed by three decades of artificial propagation of returning adults; incubation and rearing at the recipient site which enhanced imprinting of juveniles and improved homing by adults; and the use of a variety of release stages (fry to 2-yr olds).

Background

The first shipments of chinook eggs to New Zealand were made between 1876 and 1880 when approximately 500,000 ova were transported from California. These early transplants failed due to inexperience of the crew and unsuitability of the planting technique. Between 1901 and 1907, a more rigorous and systematic program was conducted. The aim of the introductions was to establish a recreational fishery on chinook in the New Zealand streams.

Transplant strategy

Between 1901 and 1907, a total of approximately 2 million eggs were transported in five shipments from a hatchery on McCloud River, a tributary to Sacramento River in northern California, to a hatchery on Hakataramea River, a tributary to Waitaki River on the South Island of New Zealand (Fig. 15). On-site incubation and rearing produced approximately 1.7 million juveniles, 90% of which were released as fry and the remainder at various sizes up to 2-yr of age. The juveniles migrated a distance of some 25 km from the hatchery to the sea. No further importations were made after 1907. When the first adults returned in 1906 until 1940, returning progeny were used exclusively as hatchery broodstock to supplement the existing runs with releases of 5 g fry.

Transplant returns

First returns of chinook were observed at the mouth of the Waitaki River in 1905. The following year, chinook were spawning in the Hakataramea River, and in 1907, a run of several hundred entered the Waitaki River and spawned in several of its major tributaries. By 1915, chinook were taken by anglers at the mouths of several South Island streams. This run subsequently extended into other South Island rivers through adult straying and extensive releases of hatchery juveniles. Chinook presently are widespread in the rivers of the east

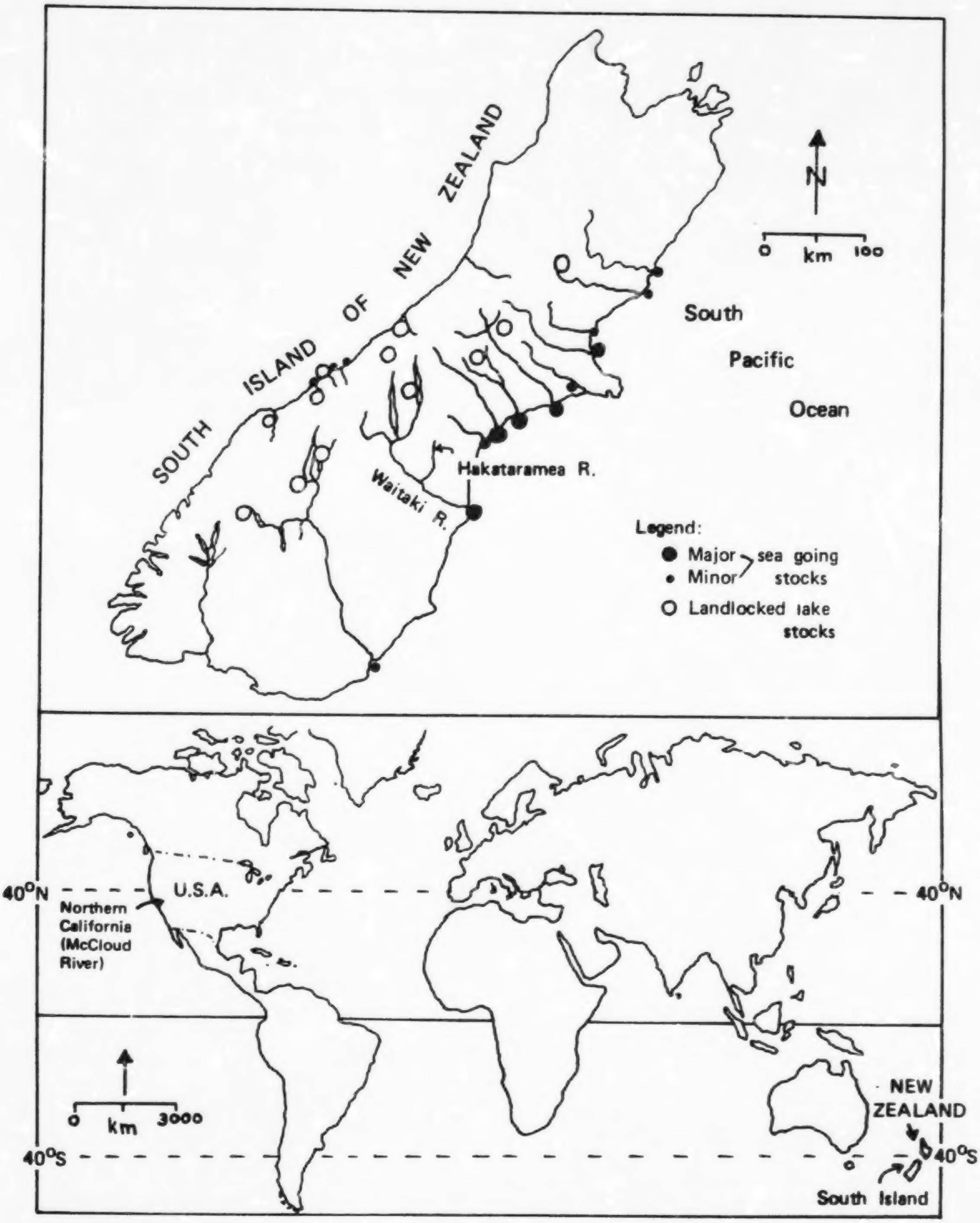
SOUTH ISLAND OF NEW ZEALAND
N
0 km 100
South Pacific Ocean
Hakataramea R.
Waitaki R.
Legend:
● Major sea going stocks
• Minor
○ Landlocked lake stocks
40°N
U.S.A.
Northern California (McCloud River)
40°N
0 km 3000
NEW ZEALAND
40°S
40°S
South Island

Fig. 15. Distribution of chinook on South Island of New Zealand (top; from McDowall 1985), and the relative location of Northern California in U.S.A. and of South Island in New Zealand (bottom).

coast of South Island and also occur in small numbers in west coast rivers where suitable chinook habitat is limited (Fig 15). Several landlocked chinook populations also became established in high elevation lakes (Fig. 15). The New Zealand chinook are a "winter" run and spawn in April, May and June. This timing in the southern hemisphere corresponds to the winter run timing of the McCloud River donor stock which spawned in October, November and December.

Suggested reasons for transplant success

Donor/recipient combination

The New Zealand rivers, many of which are glacial, generally share many physical features with the Pacific Coast rivers that support chinook populations. The Waitaki River was a good choice in that it had an especially favourable environment for natural production of chinook. The Waitaki River also provided a simple and short (25 km) migration route to the sea which the donor fish could easily negotiate.

The McCloud River in northern California which supplied the donor stock, is at the same latitude and has a similar temperature regime as the Waitaki River in New Zealand. The donor stock migrated some 300 km from its parental stream to the sea compared to the much shorter distances requried for the New Zealand rivers. The McCloud River had both summer and fall chinook runs. The former spawned from July to September; the latter which also provided the donor stock, from October to December. These populations are now extinct.

Transplant strategy

The relatively intensive transplant effort conducted over several successive years was followed by three decades of artificial propagation of returning adults. The construction of a hatchery on the Waitaki River system at the start of the program assured adequate production facilities for the rigorous and long-term propagation effort, while incubation and rearing of the transplanted eggs at the recipient site enhanced imprinting by juveniles and probably led to better homing by adults. The release of different-sized juveniles probably increased transplant success.

APPENDIX 13. CHINOOK TRANSPLANTS IN CHILE

Sources of information: FFI 1985c, 1985e; Hopkins 1985; Lindbergh et al. 1981.

Synopsis

Chile is currently introducing chinook salmon into its waters and developing salmon farming and ranching programs in an attempt to form a commercially viable salmon fishery. Initial hatchery returns indicate that this species is becoming naturalized in the Chilean waters.

Background

Between 1901 and 1930, Chile received 739,000 chinook, sockeye and coho salmon eggs. Fry were liberated into streams in southern Chile, since this region is in the same latitude as the northern half of New Zealand's South Island where successful chinook colonization was achieved in the 1900s. The early Chilean introductions were unsuccessful and a new series of attempts began in 1970.

Transplant strategy and returns

Since the mid-1970s, Chile has imported several million chinook eggs from Washington, primarily Green River stock, and from Oregon (Fig. 16). Details on donor stock characteristics and donor/recipient habitat suitability were not available in the surveyed literature. Eggs were incubated and reared in Chilean hatcheries, and the juveniles released at various sites in Chile. In one particular transplant, 120,000 spring chinook originating from the Cowlitz broodstock, Washington, were released at Curaco in southern Chile in late 1978 at about 70 g. Return of jacks and 3-yr-olds by early 1981 was estimated at 950 fish giving a 0.79% return survival. In another transplant in 1980, 280,000 eyed chinook eggs were imported from the United States to the Rio Santa Maria hatchery in southernmost Chile (Fig 16). On-site incubation and rearing resulted in a March release of approximately 200,000 juveniles at 3-4 g. Migration distance to the sea was less than 2 km. In 1984, a small number of 4-yr-old chinook returned to the release site from this transplant. The few successful returns may have been facilitated by rearing prior to the release and a short migration distance to the sea.

By 1985, Chilean salmon ranching involved annual releases of about 1-1.5 million chinook and coho smolts, with overall returns of approximately 1% each year. The returning fish are used mainly for broodstock in the hope that successive generations of "Chilean-born" fish will result in higher survival. Selection of release sites appears to be an important factor in the transplants since some sites seem to have better return rates than others.

SOCKEYE TRANSPLANTS

Despite considerable effort to introduce and reestablish sockeye in various systems (Kemmerich MS 1945; IPSFC 1950-1980; Aro 1979) success in developing self-sustaining stocks has been extremely limited. On the Pacific Coast, sockeye transplants in Lakes Washington and Frazer are the only clear examples of major sockeye transplant success. These and other successful transplants are detailed below in Appendices 14 to 17.

APPENDIX 14. SOCKEYE TRANSPLANTS IN UPPER ADAMS RIVER, BRITISH COLUMBIA

Sources of information: IPSFC 1950-1980; Williams MS 1985; I. Williams (pers. comm.); J. Woodey (pers. comm.).

Synopsis

A program to restore sockeye runs to the once very productive Upper Adams River has been conducted since 1949. Altogether, approximately 10 million eyed eggs, 0.7 million fry and 0.2 million fingerlings have been transplanted to the Upper Adams River between 1949 and 1975, using mainly the Seymour River broodstock. Spawner returns were few but they increased significantly from 560 in 1980 to 3,502 in 1984. The successful return in 1984 was attributed to the use of the nearby Momich/Cayenne sockeye for broodstock, short-term on-site rearing prior to release, a more favourable Adams Lake environment with greater zooplankton abundance, and protection from fishery exploitation.

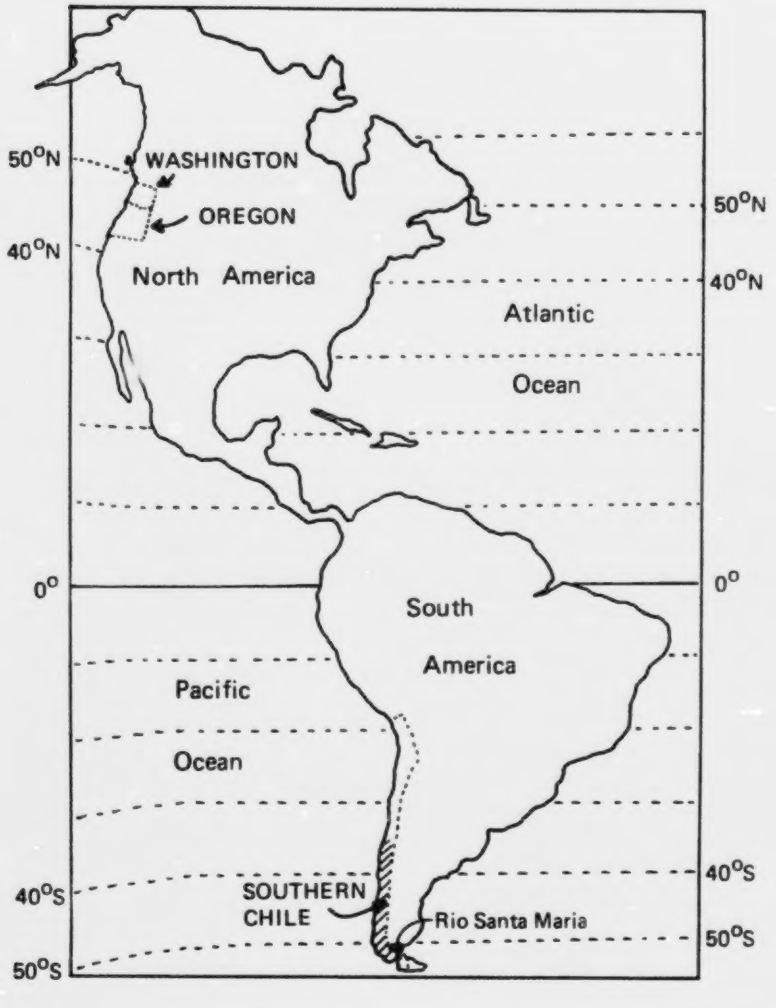
50°N
WASHINGTON
OREGON
40°N
North America
50°N
40°N
Atlantic
Ocean
0°
0°
South
America
Pacific
Ocean
40°S
SOUTHERN
CHILE
Rio Santa Maria
40°S
50°S
50°S

Fig. 16. North and South America showing the relative location of Washington and Oregon states which supplied chinook donor stocks for transplants into southern Chile (hatched area).

Background

The Upper Adams River, a major tributary to Adams Lake (Fig. 17), historically supported a large summer run of sockeye. This run became extinct after 1913 from a combination of man-made blockages at Hell's Gate on the Fraser River and construction of a splash dam on the Lower Adams River near the outlet of Adams Lake. Operation of the splash dam was discontinued in 1922 and the dam was removed in 1945. Fishways were completed at Hell's Gate in 1946, and an extensive transplant program was conducted from 1949 to 1984 to restore the run.

Transplant strategy

Initially, Seymour and Taseko Rivers, both in the Fraser River watershed (Fig. 17), provided the donor broodstocks. Cayenne Creek, a tributary to Adams Lake via Momich River (Fig. 17), contributed broodstock to the 1980 and 1984 programs when hybrid crosses were made using the Upper Adams males and Momich/Cayenne females. All donor fish were summer-run populations with similar migration timing and travel distance to the sea as the Upper Adams River. The donor sites are compared for their suitability for transplanting into the Upper Adams River in Table 20.

Between 1949 and 1984, 13 egg transplants, two advanced fry transplants and two fingerling transplants were made in the Upper Adams River. Altogether these releases involved approximately 10.4 million eggs (annual range 0.16-2.14 million), 0.7 million fry and 0.2 million fingerlings (Table 21). Methods used for egg-takes, incubation and fry rearing are discussed by Williams (MS 1985). Initially, eggs were incubated to the eyed stage at temporary field stations near the donor spawning grounds, then transported to the Upper Adams River and planted. In the early fry planting program (1949-52), fry were reared for 6.5 mo at the Horsefly Field Station, then airlifted to Adams Lake for release as fingerlings. From 1974, incubation was generally conducted at the receiving site. In contrast, the 1980 brood eggs were flown to the Cultus Lake Hatchery for incubation, then the alevins were flown in Heath trays to Adams Lake for subsequent rearing. Resultant fry were reared at the mouth of the Upper Adams River for about 31 days to about 0.16 g, then towed out for release into Adams Lake. For the 1984 brood, all incubation and rearing was conducted on-site. Fry were reared in troughs for 28 days, then released directly into the Upper Adams River at 0.24 g. A high-quality diet consisting of freeze-dried plankton was used in the 1980 and 1984 programs.

Transplant returns

No sockeye had been reported in the Upper Adams River after the Hell's Gate incident until 1954. Early returns from the 1949 to 1975 transplants were negligible until the 1980 and 1984 cycle years when 560 and 3,502 spawners respectively returned (Fig. 18). During the 1960s and 1970s, however, a sockeye run had been developing naturally in the nearby Momich/Cayenne system with the first return of several hundred sockeye observed in 1960 (Fig. 18). By 1984, the Momich/Cayenne run had grown to 5,854 adults; this run is limited as to further expansion by the restricted spawning habitat. The Momich/Cayenne run occurs primarily on the 1952 cycle - the same cycle that produced the return to the Upper Adams River in 1980. While it is possible that this run was established by strays returning from earlier transplants to the Upper Adams

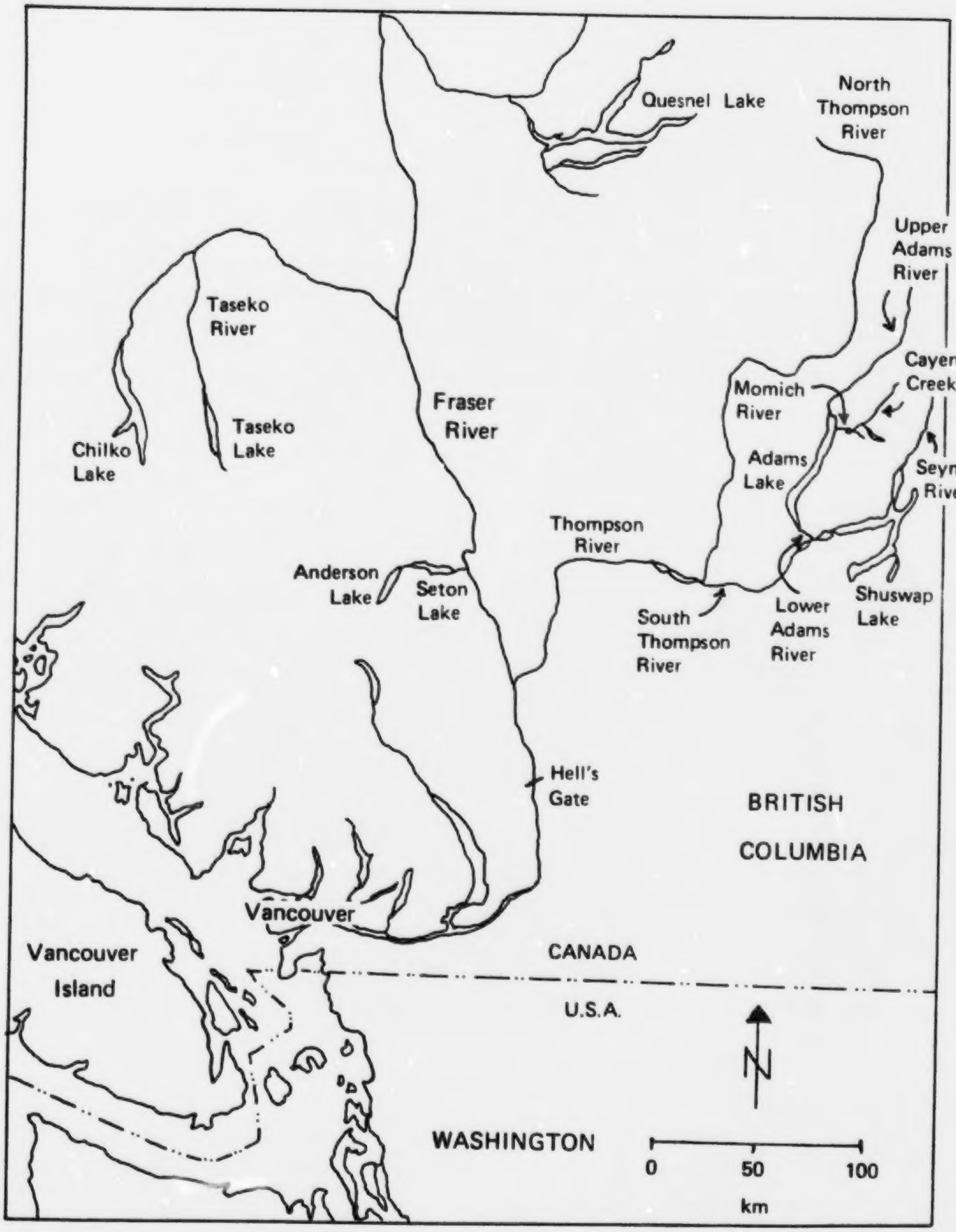
Quesnel Lake
North Thompson River
Upper Adams River
Cayenne Creek
Momich River
Adams Lake
Seymour River
Taseko River
Taseko Lake
Chilko Lake
Fraser River
Thompson River
Anderson Lake
Seton Lake
South Thompson River
Lower Adams River
Shuswap Lake
Hell's Gate
BRITISH COLUMBIA
Vancouver
Vancouver Island
CANADA
U.S.A.
N
WASHINGTON
0
50
100
km

Fig. 17. Fraser River watershed showing location of Upper Adams River, Adams Lake, Shuswap Lake, Taseko Lake and Momich-Cayenne system (from Williams MS 1985).

Table 20. Comparison of the three donor streams used in the sockeye transplants tothe Upper Adams River.[a]

Streams	Watershed	Distance of Spawning Area to Mouth of Fraser River	Distance to Upper Adams R.	Nursery Lake				
				Name	Orientation[b]	Smolt Exit Direction[b]	Temp.	Zooplankton Production (cc/1.5m3)
Receiving Site - Upper Adams	Fraser R.	520 km	0	Adams	N-S	S	Cool	Approx. 0.7
Donor Sites								
Cayenne Cr.	Fraser R.	510 km	Approx. 13 km	Adams	N-S	S	Cool	Approx. 0.7
Seymour R.	Fraser R.	540 km	Approx. 150 km	Shuswap	N-S in Seymour Arm; E-W in main arm	W	Warm	Up to 1.7
Taseko R.	Fraser R.	644 km	>500 km	Taseko	N-S	N	Cold glacial	0.03 - 0.06

[a] Information extracted from Williams (MS 1985).

[b] N - north, S - south, W - west, E - east.

Table 21. Summary of the transplants to the Upper Adams River.[a]

Brood Year	Sockeye Transplants Seymour Eggs	Taseko Eggs	Cayenne Egg	Cayenne Fry	Seymour Fingerlings	Spawner Return
1950 Cycle	667,000					194
1954	495,000					291
1958	483,000	850,000				79
1962						63
1966						4
1970						13
1974	1,374,000					0
1978						124
1982						
Total	3,019,000	850,000				768
1951 Cycle						0
1955	780,000					0
1959	900,000	600,000				5
1963						0
1967						0
1971						23
1975	2,140,000					0
1979						0
1983						
Total	3,820,000	600,000				28
1952 Cycle					187,000	9
1956	253,000					present
1960		702,000				162
1964						0
1968						31
1972						40
1976						560
1980				334,000		3,502
1984			450,000	391,000		
Total	253,000	702,000	450,000	725,000	187,000	4,304
1949 Cycle	158,000				84,000	0
1953						0
1957	520,000					0
1961						0
1965						0
1969						0
1973						0
1977						0
1981						83[b]
1985						
Total	678,000				84,000	83
Overall Total	7,770,000	2,152,000	450,000	725,000	187,000	5,183

TOTAL EGGS:	10,372,000
TOTAL FRY:	725,000
TOTAL FINGERLINGS:	187,000

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[a] Extracted from Williams (MS 1985).

[b] Estimated 69 spawners are 5-yr fish from the 1980 brood.

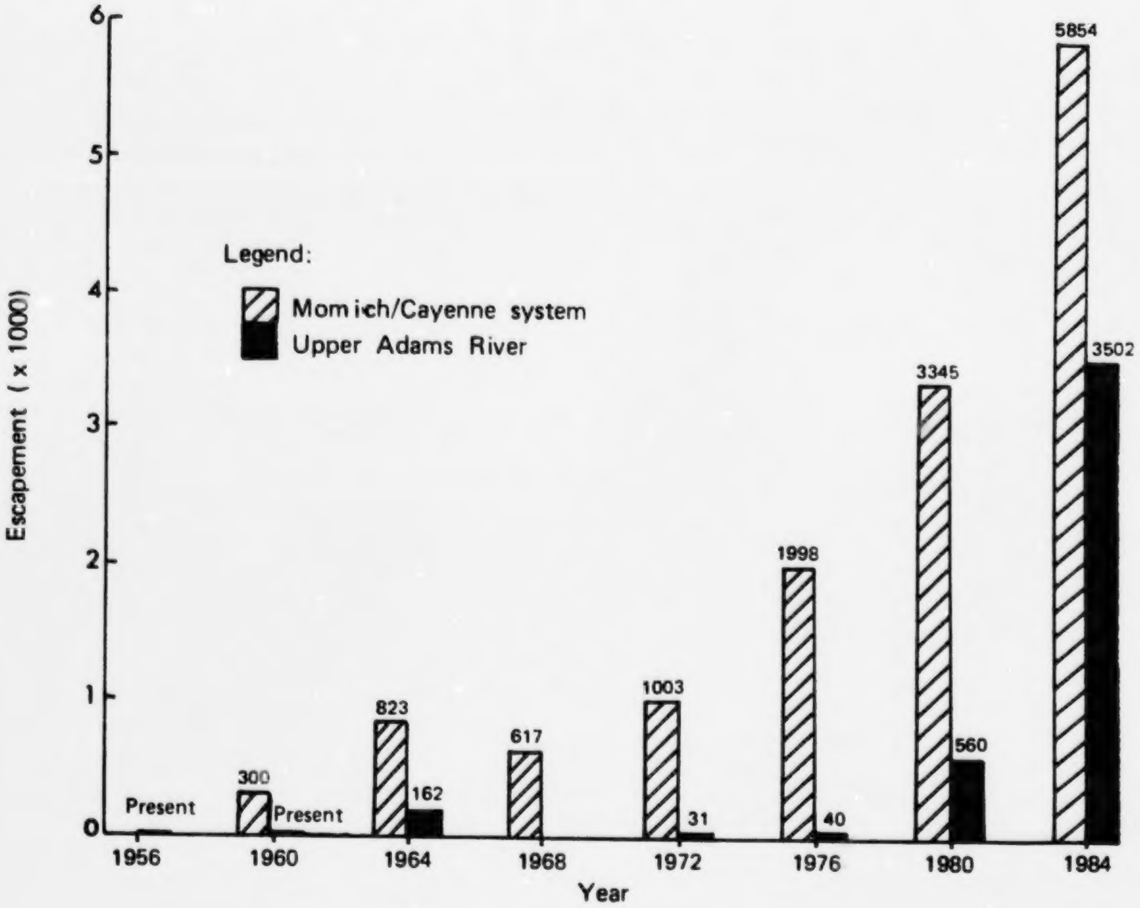


Fig. 18. Sockeye escapements in the Momich-Cayenne system and in the Upper Adams River for the 1952 cycle, 1956 - 1984.

River, no direct evidence is available.

Project assessment

Sockeye spawners are regularly enumerated in the Adams Lake watershed. Occasional smolt migration surveys are also made. In addition, Adams Lake is monitored for seasonal temperature, turbidity and plankton abundance.

Early negligible sockeye returns were probably partly due to insufficient size and intensity of transplants, and use of a genetically unsuitable donor stock. Although the majority of the donor fish came from Seymour River which was geographically close to the Upper Adams River, had similar water temperature regime during the spawning and incubation periods, and had a similar migration distance to the sea as the receiving system, the complexity of the South Thompson migration route may have caused problems during smolt and adult migrations.

The major increase in escapement to 3,502 spawners in 1984 suggested a very successful return from the 1980 hybridized transplant. However, the actual effect of hybridization cannot be quantified for several reasons. The hybrid fry were not marked, and the historical spawning records for the area are poor. Also, escapements were good for most stocks spawning in the Fraser River watershed in 1984, indicating that this was a generally good year for sockeye returns in that area (J. Woodey, pers. comm.). Since 1984 was the first large adult return to the Upper Adams River, future escapements should clarify the contribution of subsequent hybrid transplants.

Suggested reasons for apparent transplant success

Donor/recipient combination

The Upper Adams River originally supported a large sockeye run, with the downstream Adams Lake capable of supporting the progeny of some 300,000 female sockeye. Man-made obstructions were the only reason for the extinction of this run. Since the Momich River enters Adams Lake only some 10 km below the outlet of the Upper Adams River, the Momich/Cayenne run was considered to be a highly suitable broodstock for further expansion of the Upper Adams run.

Transplant strategy

Fishways completed at Hell's Gate in 1946 restored access to upstream sockeye migrants. The 1980 and 1984 hybrid programs involving the crossing of Momich/Cayenne females with Upper Adams males, provided an excellent way for expanding the small Upper Adams broodstock and probably resulted in more successful smolt outmigration and adult return. Short-term rearing of fry for several weeks prior to release at about 0.2 g probably increased fry-to-smolt survival.

Other

Protection from fishery exploitation and generally good environmental conditions favouring the 1980 sockeye run probably contributed to the good spawner return in 1984.

APPENDIX 15. SOCKEYE TRANSPLANTS IN GREAT CENTRAL LAKE, BRITISH COLUMBIA

Sources of information: Hyatt and Steer MS 1985; K. Hyatt (pers. comm.); P. Rankin (pers. comm.).

Synopsis

Between 1921 and 1932, approximately 20 million eyed sockeye eggs were transported from Henderson Lake to the Great Central Lake system on Vancouver Island (Fig. 19). The return of thousands of adults to the Stamp River in 1925 and 1926 prompted the construction of a fishway at the Stamp River Falls in 1927. The combined effect of removing a major barrier to allow upstream sockeye access and the massive annual egg plants conducted for a full decade resulted in the development of a successful self-sustaining run in the Great Central Lake system.

Background

Spawning records indicate that historically Great Central Lake had a small native sockeye population, but that the run was intermittent and often neared extinction over long periods due to the frequently impassable Stamp River Falls. The sockeye run into nearby Sproat Lake was stronger, but also experienced access problems due to the Sproat River Falls.

Sockeye eggs were planted in both systems between 1921 and 1932, to establish a run in Great Central Lake and supplement the natural production in Sproat Lake.

Transplant strategy

Between 1921 and 1932, approximately 2 million eyed sockeye eggs were planted annually in Great Central Lake tributaries, for a total of about 20 million eggs (Table 22). Most eggs were planted in Drinkwater Creek, the headwater tributary of Great Central Lake (Fig. 19). The donor stock came from Henderson Lake, located approximately 60 km south of Great Central Lake (Fig. 19). Fishways constructed at Stamp Falls (1927), the Great Central Lake outlet (1929) and Sproat Falls (1951) greatly aided in the colonization of these areas.

Transplant returns

The first 2.7 million eyed eggs planted in 1921 in the Great Central Lake system resulted in over 5,000 adults returning in 1925 to the base of Stamp Falls. Low water levels from July to September blocked salmon access at the falls and the sockeye died unspawned. In 1926, 11,000 sockeye adults were dip-netted over the falls but thousands more died unspawned below the barrier. With the construction of a fishway at Stamp Falls in 1927, access to sockeye spawners was assured and the run continued to develop reaching 50,000 by 1950 (Fig. 20). Sockeye spawners were also observed in McCoy Lake which received about 1 million eggs between 1922 and 1925 (Table 22).

Suggested reasons for transplant success

Donor/recipient combination

Great Central Lake was capable of supporting a sockeye run, as indicated by the intermittent reports of a residual population. A physical barrier at the

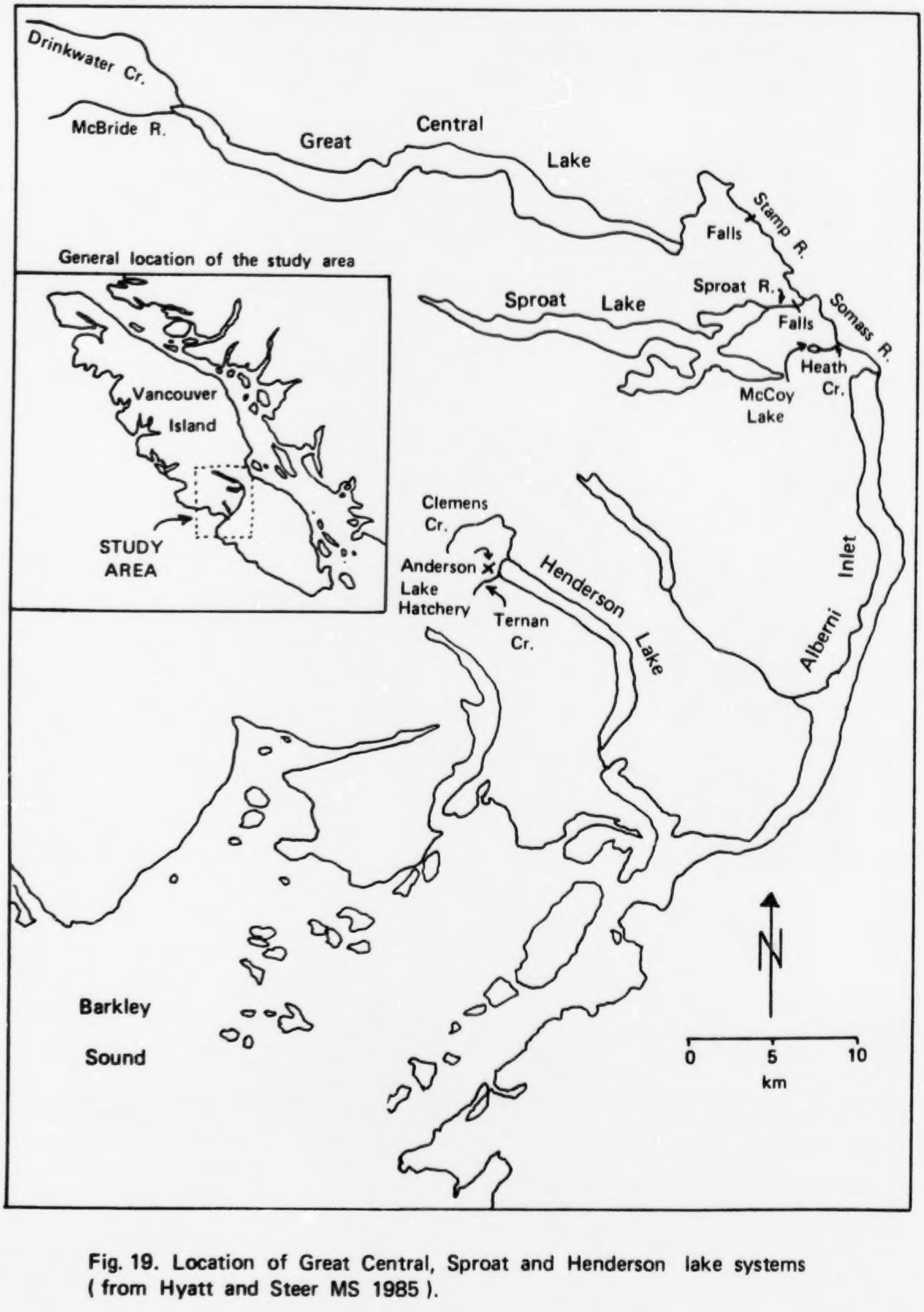

Drinkwater Cr.
McBride R.
Great Central Lake
Stamp R.
Falls
Sproat Lake
Sproat R.
Falls
Somass R.
Heath Cr.
McCoy Lake
General location of the study area
Vancouver Island
STUDY AREA
Clemens Cr.
Anderson Lake Hatchery
Ternan Cr.
Henderson Lake
Alberni Inlet
Barkley Sound
N
0
5
10
km

Fig. 19. Location of Great Central, Sproat and Henderson lake systems (from Hyatt and Steer MS 1985).

Table 22. Transplants of sockeye eggs into the McCoy Lake, Great Central Lake and Sproat Lake systems, 1921 - 1932 broods.[a]

Brood Year	Collecting and Eyeing Hatchery	Source of Eggs	Distribution of Eggs		
			McCoy Lake	Great Central Lake	Sproat Lake
1921	Anderson Lake	Clemens Creek and Henderson Lake beaches	0	2,688,000	1,312,000
1922	Anderson Lake	Clemens and Ternan Creeks and Henderson Lake beaches	250,000	1,996,000	1,456,000
1923	Anderson Lake	Henderson Lake beaches	252,000	2,002,000	2,002,000
1924	Anderson Lake	Henderson Lake beaches	252,000	2,002,000	2,002,000
1925	Anderson Lake	Clemens Creek and Henderson Lake beaches	252,000	2,002,000	2,002,000
1926	Anderson Lake	Clemens Creek and Henderson Lake beaches	0	2,002,000	2,002,000
1927	Anderson Lake	Henderson Lake beaches	0	2,002,000	2,002,000
1928	Anderson Lake	Henderson Lake beaches	0	2,002,000	2,002,000
1929	Anderson Lake	Henderson Lake beaches	0	1,505,000	2,002,000
1932	Anderson Lake	Henderson Lake beaches	0	2,002,000	2,002,000
Total Eggs			1,006,000	20,203,000	18,287,000

[a] Extracted from Hyatt and Steer (MS 1985).

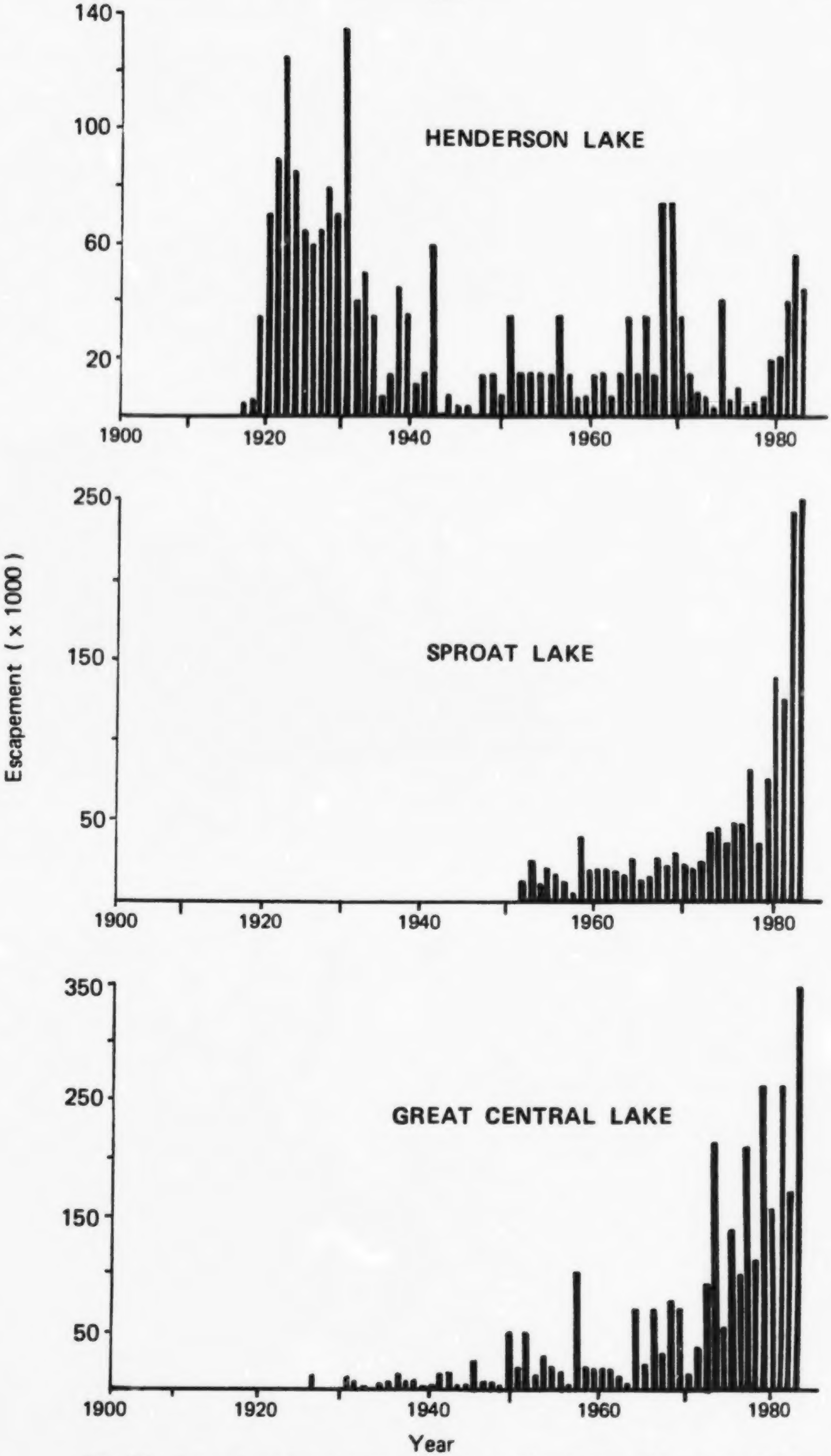


Fig. 20. Annual sockeye escapements to Henderson, Sproat and Great Central Lakes, 1903 - 1983 (from Hyatt and Steer MS 1985).

Stamp River Falls was the only apparent reason for the negligible sockeye production in the system. Although a single Henderson Lake donor stock was used in egg transplants to Great Central Lake, the donor and receiving systems were apparently well matched. The Henderson and Great Central Lakes are about 60 km apart, have similar lake orientation and general direction of exit, and both flow into Barkley Sound (Fig. 19).

Transplant techniques

The Stamp Falls fishway was critical in providing access to sockeye transplant progeny returning to Great Central Lake. The intensive transplant effort, averaging approximately 2 million eggs each year and maintained for a full decade, provided a strong genetic base and facilitated the development of Great Central Lake broodstock. Planting of eggs primarily into the headwater tributary of the Great Central Lake probably enhanced juvenile imprinting and subsequent homing by adults past the parental Henderson Lake into Great Central Lake.

APPENDIX 16. SOCKEYE TRANSPLANTS IN FRAZER LAKE, ALASKA

Sources of information: Blackett 1979; R. Blackett (pers. comm.).

Synopsis

A significant and highly successful, self-sustaining sockeye run has been developed in the previously inaccessible Frazer Lake watershed on Kodiak Island, Alaska. Nearby Red Lake provided the donor broodstock. The intensive transplant program spanned a decade between 1961 and 1971 and utilized a variety of life history stages including nearly 30,000 adults, 3 million fry and about 8 million eggs. Escapements to Frazer Lake increased steadily from several hundred in the early 1960s to about 400,000 during the 1980s. The success of this transplant is attributed in part to the use of a suitable nearby donor stock for long-term and large-scale transplants; a combination of egg, fry and adult transplants; and protective commercial fishing closures.

Background

Frazer Lake (Fig. 21) was historically barren due to a 10 m high falls in the outlet stream. Preliminary studies in the 1950s indicated there were suitable sockeye spawning and rearing areas in the Frazer Lake watershed, rendering it a good candidate for a sockeye colonization program. These preliminary studies also included a survey of resident potential competitors and predators.

Transplant strategy

Three million eggs from Karluk Lake were planted in the Frazer Lake watershed between 1951 and 1956. This was followed by an intensive, long-term transplant program between 1961 and 1971 when approximately 8 million eggs, 3 million fry and nearly 30,000 adults were planted in the Frazer Lake watershed using the Red Lake donor stock (Table 23) in preference to the weaker Karluk Lake stock. In 1962, when the success of the sockeye transplant became apparent, a fishway was constructed at the impassable falls.

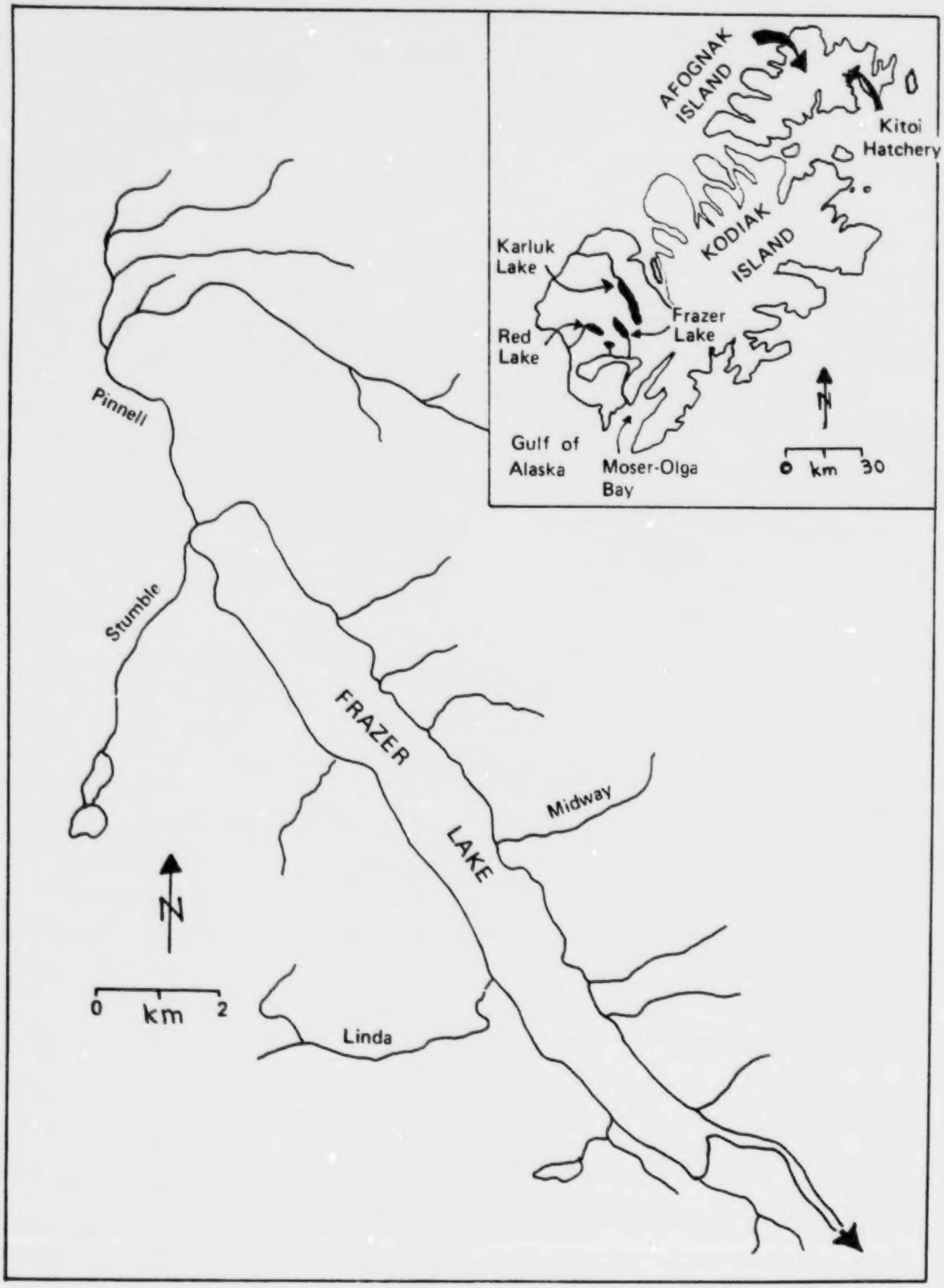

AFOGNAK ISLAND
Kitoi Hatchery
KODIAK ISLAND
Karluk Lake
Red Lake
Frazer Lake
Gulf of Alaska
Moser-Olga Bay
0 km 30
Pinnell
Stumble
FRAZER LAKE
Midway
Linda
N
0 km 2

Fig. 21. Frazer Lake system and location of Frazer, Karluk and Red Lakes on Kodiak Island, Alaska (from Blackett 1979).

Table 23. Sockeye transplants, adult returns and return in relation to parent year escapement at Frazer Lake, Alaska 1951-1985.[a]

Year	TRANSPLANTS				Annual Escapement[c]	Estimated Catch[d]	Estimated Total Return[d]	Return Produced by Parent Year Escapement[e]	Return per Spawner
	Adults	Fry	Eggs						
			Eyed	Green					
1951-1955[b]	0	0	320,000	2,146,000	-	-	-	-	-
1956[b]	0	0	500,000	0	6	-	-	-	-
1957	0	0	0	0	165	-	-	-	-
1958	42	0	0	0	71	-	-	-	-
1959	0	0	0	0	62	-	-	-	-
1960	0	0	0	0	440	-	-	-	-
1961	600	87,000	0	0	273	-	-	-	-
1962	1,800	0	0	0	1,290	-	-	-	-
1963	9,500	0	0	0	2,357	-	-	-	-
1964	1,800	0	0	0	9,966	-	-	-	-
1965	4,000	0	830,000	0	9,074	-	-	-	-
1966	4,728	504,000	600,000	0	16,456	-	-	33,669[f]	2.05[f]
1967	7,334	0	1,190,000	0	21,834	-	-	86,476	3.96
1968	30	312,000	3,387,000	0	16,738	-	-	59,800	3.57
1969	60	600,000	1,963,000	0	14,041	-	-	68,073	4.85
1970	0	945,000	0	0	24,039	-	-	73,605	3.06
1971	0	527,000	0	0	55,366	-	-	123,310	2.23
1972	0	0	0	0	66,419	-	-	167,599	2.52
1973	0	0	0	0	56,255	-	-	57,640	1.02
1974	0	0	0	0	82,609	-	-	176,956	2.14
1975	0	0	0	0	64,199	-	-	253,367	3.95
1976	0	0	0	0	119,300	-	-	586,727	4.92
1977	0	0	0	0	139,548	-	-	352,876	2.53
1978	0	0	0	0	141,981	-	-	197,911[f]	1.39[f]
1979	0	0	0	0	126,742	-	-	23,807[f]	0.19[f]
1980	0	0	0	0	405,525	-	-	-	-
1981	0	0	0	0	377,716	151,000	529,000	-	-
1982	0	0	0	0	437,772	54,000	492,000	-	-
1983	0	0	0	0	158,340	40,000	198,000	-	-
1984	0	0	0	0	53,524	18,000	72,000	-	-
1985	0	0	0	0	485,835	165,000	651,000	-	-
Total	29,894	2,975,000	8,790,000	2,146,000	-	-	-	-	3.16[g]

[a] Data for 1951 to 1978 from Blackett (1979); data for 1979 to 1985 from R. Blackett (pers. comm.).

[b] Karluk Lake donor; thereafter, Red Lake donor.

[c] Sockeye counted at the top of the fish pass or back-packed over the falls prior to 1963.

[d] Catch data unavailable until 1981.

[e] Used escapement returns only, since catch data not available.

[f] Incomplete returns.

[g] Only complete returns used.

Red Lake, a major sockeye producer, was selected as the primary donor stock. This lake is geographically close to and has similar physical and environmental features as Frazer Lake (Fig. 21). Sockeye spawn in both the Red Lake and its tributaries but mostly tributary spawners were used for the egg-takes. In order to create an early run timing at Frazer Lake and avoid unmanageable mixed stock fisheries in the Moser-Olga Bay area (Fig. 21), the June to July portion of the Red Lake run was selected for egg-takes and adult transplants.

Eggs were collected at Red Lake and flown to the Kitoi hatchery on nearby Afognak Island (Fig. 21) for incubation to the eyed egg or fry stages. Eyed eggs were planted manually at up to 20,000-25,000 eggs per redd, usually at a well developed egg-stage (2-3 wk before hatching) to shorten the incubation period at high egg concentration before alevin dispersal in gravel. Fry were incubated and reared for about 1 mo to about 0.15 g at the Kitoi hatchery, then airlifted to Frazer Lake in May and June. To enhance imprinting, some groups of fry were released in the main inlet stream at the lake head. During adult transplants, fish were airlifted from Red Lake for release in Frazer Lake. A weir across the Frazer Lake outlet prevented exit of transported adults from the lake.

Transplant returns

Since the first egg transplants to Frazer Lake in 1951, sockeye escapements have increased gradually over the years from several hundred in the early 1960s to around 400,000 in the 1980s, with a mean of 3.2 returns/spawner for the 1966-77 brood years (Table 23). This run is now self-sustaining and provides significant benefits to commercial fisheries in the Kodiak area. As sockeye returns to Frazer Lake have increased, sockeye spawning has extended into new areas through adult straying. The timing, age and size structure of the Frazer Lake sockeye is similar to that of the early portion of Red Lake run.

Project assessment

The relative success of different planting products (eggs, fry and adults) at Frazer Lake could not be evaluated since these were used in combination. However, fry plantings likely produced the highest survival to smolt stage.

Frazer Lake is assessed annually to determine adult abundance and composition at the fishway, spawning area distribution and utilization, and smolt abundance, size and timing. Lake studies are also conducted to determine the seasonal zooplankton abundance and composition, water temperature and chemistry, distribution of rearing sockeye juveniles, and optimal lake spawning and rearing capacity.

At present, sockeye production in Frazer Lake appears to be unstable. This is indicated by greatly reduced smolt size and condition factor, changes in zooplankton composition and density, and severe fluctuations in returns/parent year spawner (R. Blackett, pers. comm.). Project evaluation continues to be required to assess long-term escapement goals, smolt production and changes in lake productivity, and to develop a more effective strategy to manage the harvest in a mixed-stock fishery.

Suggested reasons for transplant success

Donor/recipient combination

Frazer Lake was an excellent candidate for a sockeye transplant for several reasons. Preliminary studies indicated good potential spawning and rearing production capacities. The impassable falls in the outlet stream appeared to be the only reason for the barren state of this watershed. The nearby Red and Karluk Lakes were both excellent sockeye producers and were similar physically and environmentally to Frazer Lake, further suggesting that Frazer Lake also had a good potential for sockeye production.

Red Lake on Kodiak Island was selected as the geographically closest (80 km from Frazer Lake) donor stock which could provide large quantities of broodstock annually for Frazer Lake transplants. The donor system closely matched the Frazer Lake system in biological and physical parameters such as quality and quantity of rearing area, the presence of tributaries, similar oligotrophic state with high quality, clear water, and similar length of the freshwater migration route. Note however, that the exit orientation differs in the two systems (Fig. 21).

Transplant strategy

The success of the Frazer Lake transplant is attributed largely to an intensive and prolonged transplant program conducted over a decade. Equally important was a fishway constructed in 1962 which opened the recipient site to natural spawning. The use of a combination of adult, fry and egg planting methods likely increased the probability of transplant success, with fry transplants probably resulting in higher survival to smolt stage than egg or adult transplants. Fry and adult releases into Frazer Lake rather than only into suitable rearing and spawning areas, probably increased straying of returning adults within the Frazer system and hastened watershed colonization.

Other

Commercial fishing restrictions implemented annually to protect the Frazer Lake sockeye salmon favoured escapement to that system especially during the initial establishment of the run.

APPENDIX 17. SOCKEYE TRANSPLANTS IN LAKE WASHINGTON, WASHINGTON

Sources of information: Royal and Seymour 1940; Kemmerich MS 1945, MS 1951; Kolb 1971; Ricker 1972; Anon. 1982, 1985b; J. Ames (pers. comm.).

Synopsis

A major self-sustaining sockeye run, presently estimated at around 300,000 spawning adults, has been developed in the Lake Washington system. Over the long-term outplanting program between 1935 and 1963, approximately 5 million sockeye juveniles were released into this watershed. The nearby Baker River in the Skagit system provided the initial donor stock. Subsequent hatchery broodstock was derived from transplant progeny returning to the Lake Washington system.

Background

Historically, Lake Washington was famous for its kokanee populations although some sockeye were probably also present. Native kokanee were also found in nearby Lake Sammamish (Fig 22). In 1916, a ship canal with locks was completed, linking Lake Washington directly to Puget Sound. The result was that the Black River, which originally connected Lake Washington to the sea, dried out, and Cedar River, which flowed into the Black River at a point approximately 1 km blow the Lake Washington outlet, was diverted into Lake Washington to supply more water (Fig. 23). With this diversion, the Cedar River with its extensive but unused spawning area became a potential sockeye producer, with Lake Washington providing a large downstream nursery area.

Transplant strategy

The record of sockeye transplant releases into the Lake Washington system is given in Table 24. Starting in 1935, sockeye fry and fingerlings were outplanted mainly into Issaquah Creek (Fig. 22). During the 18 annual outplants conducted between 1935 and 1963, a total of 4,956,230 sockeye juveniles ranging in size from 0.15 g fry to 8.1 g yearlings, were released in the Lake Washington system. Annual releases averaged around 275,000 juveniles (range 5,000 in 1957 - 2.5 million in 1937). Nearly all the transplants originated from Baker River, located in the Skagit system about 70 km north of Lake Washington (Fig. 22). Sockeye from the Skagit system represented the only natural sockeye run in the Puget Sound area and the nearest potential donor stock for the Lake Washington system. Minor introductions were made using the Cultus Lake and University of Washington stocks (Table 24).

Initially, sockeye were reared in Birdsview hatchery on Grandy Creek, a tributary to the Skagit River (Fig. 22), then transported to the Lake Washington system for release into lakes and streams. A portion of the juveniles were also reared for up to 3 wk at the Issaquah hatchery located upstream of Lake Washington (Fig. 22) for imprinting purposes. Beginning in 1947, all rearing took place in the Issaquah hatchery and only hatchery returns were utilized for broodstock (Table 24). During the 1970s, further efforts were made to increase sockeye production in Lake Washington through infusion of hatchery-reared juveniles originating from the local broodstock. However, these enhancement efforts failed due to rearing losses from IHN outbreaks (J. Ames, pers. comm.). It should be noted that the Baker River donor stock is IHN-free, which allowed the successful hatchery rearing of the initial transplants. However, since the IHN virus is present in the Lake Washington waters, it infected the introduced stock and became a serious problem under hatchery conditions.

Transplant returns

Until the late 1950s, sockeye returns to the Lake Washington system (Table 24) were poorly monitored and negligible except for a spectacular escapement of 9,099 adults to Issaquah Creek in 1940. Returns, especially to the Cedar River, increased dramatically in the early 1960s and ranged between 100,000 and 370,000 during the 1964-84 period. Note that although accurate escapements for Cedar River are not available (J. Ames pers. comm.), they closely parallel the total system escapements. Presently, up to 90% of the run spawn naturally in Cedar River and the remainder spawn in Bear and Issaquah

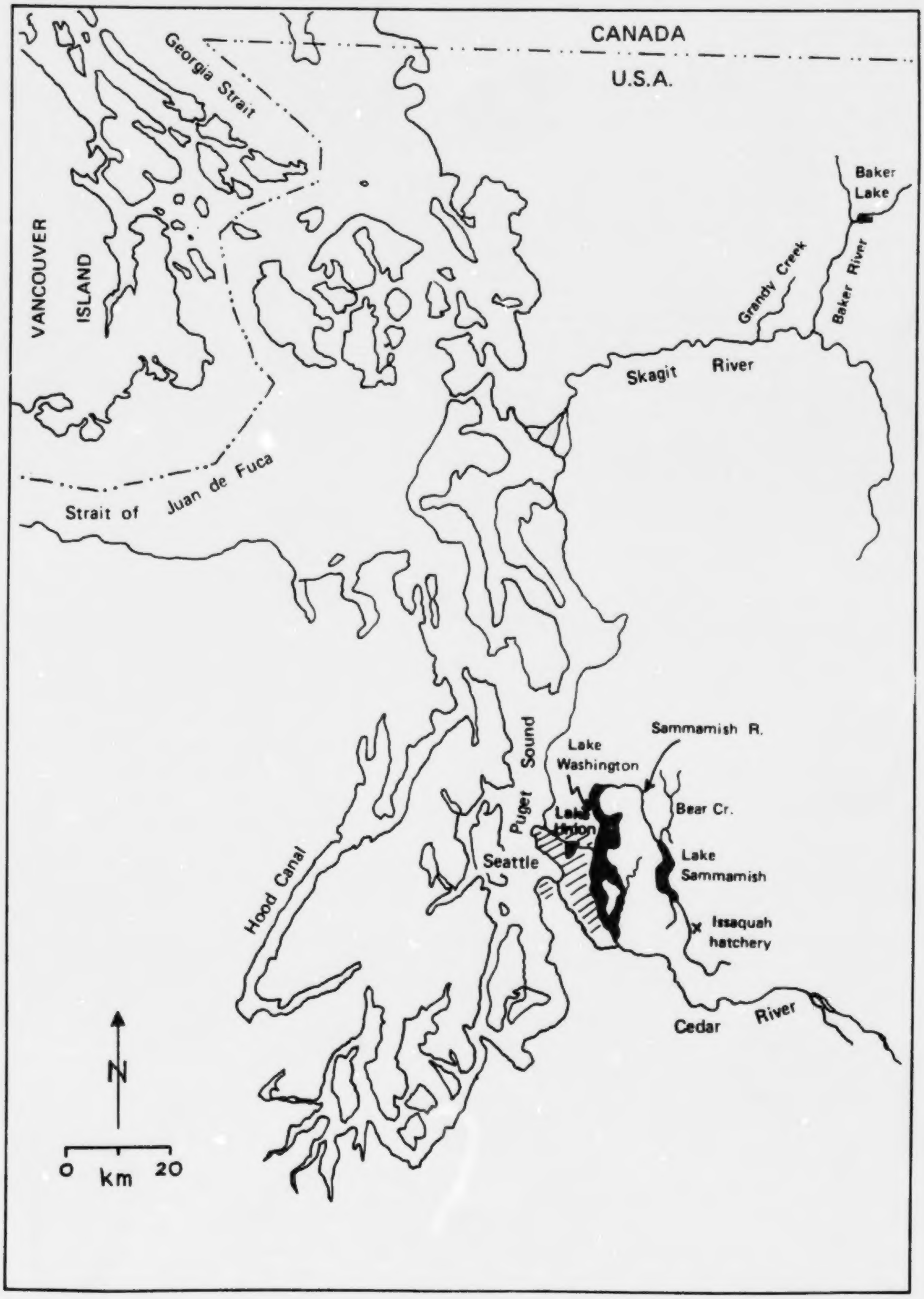
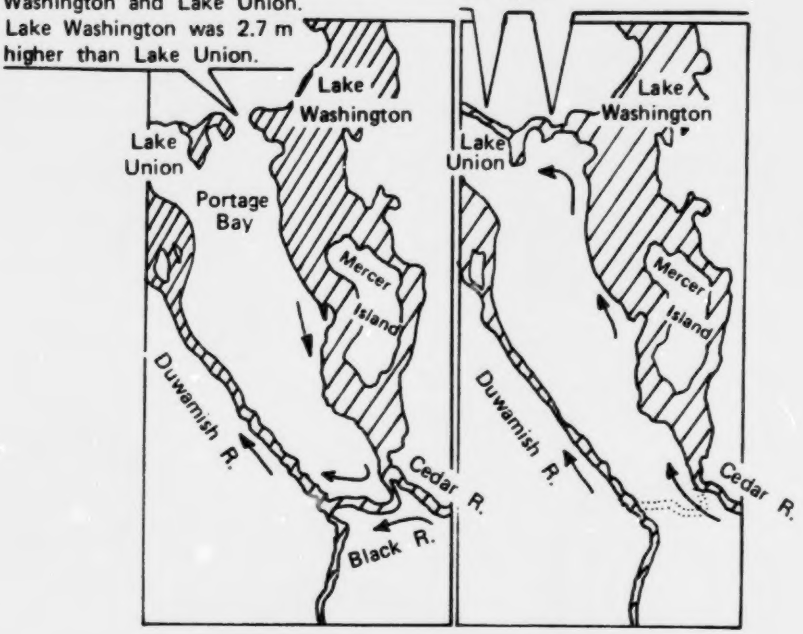

CANADA
U.S.A.
Georgia Strait
VANCOUVER ISLAND
Baker Lake
Grandy Creek
Baker River
Skagit River
Strait of Juan de Fuca
Puget Sound
Sammamish R.
Lake Washington
Lake Union
Bear Cr.
Lake Sammamish
Issaquah hatchery
Seattle
Hood Canal
Cedar River
N
0 km 20

Fig. 22. Lake Washington and the surrounding area (from Royal and Seymour 1940).


Lake Union
Portage Bay
Lake Washington
Mercer Island
Duwamish R.
Cedar R.
Black R.
Lake Union
Lake Washington
Mercer Island
Duwamish R.
Cedar R.

Originally there was no natural connection between Lake Washington and Lake Union. Lake Washington was 2.7 m higher than Lake Union.

The Ship Canal connects Lake Washington and Puget Sound, the 'new' route to the ocean for sockeye.

Pre-1916: The ancient Cedar River is believed to have contained runs of chinook, coho, pink and chum salmon, but no sockeye salmon. Salmon spawning in the Sammamish River, which enters the north end of the Lake, migrated to sea by swimming south through the Lake and out the Black River, into the Duwamish and finally Elliott Bay. Salmon spawning in the Cedar River migrated to salt water via the old Black River and the Duwamish River.

Post-1916: Opening of the Ship Canal in 1916 caused a reversal of the lake drainage, and made a new route to sea for migrating salmon. The canal opening caused the lake to drop 2.7 m and the Black River to dry up. The Cedar was diverted into the lake. Young sockeye emerging from gravel in the Cedar, drift to the lake where they spend a year before going to sea.

Fig. 23. Lake Washington before and after the Cedar River diversion; arrows indicate direction of flow (from Anon 1985b).

Table 24. Sockeye transplants and returns to Lake Washington system, 1935-1984.[a]

	ANNUAL TRANSPLANTS				ANNUAL ESCAPEMENTS [b]			
Year	Release Area (Fig. 22)	Number Released	Size (g)	Egg Source (H = hatchery)	Cedar River	Issaquah Creek	Total System	Number of Eggs Taken Artificially
1935	Cedar River	96,000	Fingerling	Birdsview H. [c]	No survey	-	-	-
1935	Issaquah Cr.	76,000	Fingerling	Birdsview H.	"	-	-	-
1936	d	-	-	-	"	-	-	-
1937	Cedar River	656,000	Fry	Birdsview H.	"	-	-	-
	Issaquah Cr.	1,257,000	Fry/fingerling	Birdsview H.	"	-	-	-
	Bear Creek	576,000	Fry	Birdsview H.	"	-	-	-
1938	e	-	-	-	"	-	-	-
1939	e	-	-	-	"	-	-	-
1940	e	-	-	-	"	9,099	10,000+	837,781
1941	e	-	-	-	"	562	562+	60,330
1942	Lake Washington	41,065	Fingerling	Birdsview H.	"	19	19+	-
1943	Cedar River	227,139	Fingerling	Birdsview H.	"	8	8+	-
	Issaquah Cr.	254,298	Fingerling	Birdsview H.	"	-	-	-
1944	North Creek [f]	23,655	0.7	Cultus Lake	"	203	294+	-
	Issaquah Cr.	41,761	Yearling	Birdsview H.	"	-	-	-
	Cedar River	7,000	Yearling	Birdsview H.	"	-	-	-
	Cedar River	37,530	Fingerling	Birdsview H.	"	-	-	-
	Cedar River	10,000	Fry	Birdsview H.	"	-	-	-
	Cedar River	32,012	Yearling	Birdsview H.	"	91	-	-
1946	-	-	-	-	"	482	482+	35,450
1947	Issaquah Cr.	782	6.7	Issaquah H.	"	509	509+	93,007
	Issaquah Cr.	11,898	0.2	Issaquah H.	"	-	-	-
	Issaquah Cr.	19,447	1.2	Issaquah H.	"	-	-	-
1948	Issaquah Cr.	7,696	5.0	Issaquah H.	"	262	262+	152,474
	Issaquah Cr.	33,424	1.0	Issaquah H.	"	-	-	-
1949	Issaquah Cr.	81,151	8.1	Issaquah H.	"	29	29+	25,617
	Issaquah Cr.	47,920	0.5	Issaquah H.	"	-	-	-
	Issaquah Cr.	8,000	2.4	Issaquah H.	"	-	-	-
1950	Issaquah Cr.	5,629	Fingerling	Cultus Lake	"	399	399+	155,322
	Issaquah Cr.	20,246	1.6	Issaquah H.	"	-	-	-

Table 24 (cont'd).

	ANNUAL TRANSPLANTS				ANNUAL ESCAPEMENTS b			
Year	Release Area (Fig. 22)	Number Released	Size (g)	Egg Source (H = hatchery)	Cedar River	Issaquah Creek	Total System	Number of Eggs Taken Artificially
1951	Lake Union	19,344	0.9	Issaquah H.	No survey	176	176+	112,024
	Issaquah Cr.	104,720	1.8	Issaquah H.	"	-	-	-
1952	Issaquah Cr.	7,824	3.5	Issaquah H.	"	148	148+	153,216
	Issaquah Cr.	75,737	0.6	Issaquah H.	"	-	-	-
1953	Issaquah Cr.	713	6.9	Issaquah H.	"	22	22+	7,000
	Issaquah Cr.	14,237	0.4	Issaquah H.	"	-	-	-
1954	Issaquah Cr.	910	6.5	Issaquah H.	"	1,909	1,909+	138,040
	Issaquah Cr.	53,984	3.2	Cultus Lake	"	-	-	-
1955	Issaquah Cr.	18,999	2.5	Issaquah H.	"	723	723+	155,100
	Lake Union	54,814	Fingerling	Univ. Wash.	"	-	-	-
1956	Issaquah Cr.	82,016	1.3	Issaquah H.	"	38	38+	5,000
	Issaquah Cr.	46,641	3.3	Issaquah H.	"	-	-	-
1957	Lake Sammamish	4,950	0.15	Issaquah H.	"	87	87+	-
1958	-	-	-	-	"	6,289	6,289+	357,500g
1959	-	-	-	-	"	840	840+	-
1960	-	-	-	-	N/A i	25,141	25,141+	1,624,373h
1961	Cedar River	118,720	0.4	Issaquah H.	"	10,078	10,078+	-
	Lake Sammamish	107,250	0.2	Issaquah H.	"	-	-	-
	Issaquah Cr.	295,740	0.4	Issaquah H.	"	-	-	-
	Issaquah Cr.	162,180	0.6	Issaquah H.	"	-	-	-
1962	-	-	-	-	"	5,867	5,867+	249,100
1963	Issaquah Cr.	221,398	0.3	Issaquah H.	"	149	149+	-
	Issaquah Cr.	4,400	2.1	Issaquah H.	"	-	-	-
1964	-	-	-	-	"	4,771	137,500	-
1965	-	-	-	-	"	965	132,000	-
1966	-	-	-	-	"	-	123,000	-
1967	-	-	-	-	"	214	383,000	-
1968	-	-	-	-	"	420	252,000	-
1969	-	-	-	-	"	193	200,000	-
1970	-	-	-	-	"	81	124,000	-
1971	-	-	-	-	"	N/A	183,000	-

Table 24 (cont'd).

	ANNUAL TRANSPLANTS				ANNUAL ESCAPEMENTS [b]			
Year	Release Area (Fig. 22)	Number Released	Size (g)	Egg Source (H = hatchery)	Cedar River	Issaquah Creek	Total System	Number of Eggs Taken Artificially
1972	-	-	-	-	N/A	N/A	249,000	-
1973	-	-	-	-	"	"	330,000	-
1974	-	-	-	-	"	"	126,000	-
1975	-	-	-	-	"	"	120,000	-
1976	-	-	-	-	"	"	159,000	-
1977	-	-	-	-	"	"	435,000	-
1978	-	-	-	-	"	"	290,000	-
1979	-	-	-	-	"	"	206,000	-
1980	-	-	-	-	"	"	361,000	-
1981	-	-	-	-	"	"	107,000	-
1982	-	-	-	-	"	"	289,000	-
1983	-	-	-	-	"	"	227,000	-
1984	-	-	-	-	"	"	372,000	-
Total	-	4,956,226	-	-	-	-	-	-

[a] Sources of information: 1935 to 1963 data from Kolb (1971); 1964 to 1981 data from Anon. (1982); 1982 to 1984 data from J. Ames (pers. comm.).

[b] Adult counts for 1940 to 1969 were provided by Issaquah Hatchery.

[c] Former U.S. Bureau of Fisheries hatchery on Grandy Creek, a tributary of Skagit River. Hatchery was closed on July 1, 1947.

[d] 1935 broodstock did not survive; therefore, no plants were made in 1936.

[e] No eggs provided by Birdsview Hatchery.

[f] North Creek is located at the northern end of Lake Washington.

[g] These eggs were planted in Baker Lake.

[h] This count includes 144,110 eggs from the Cedar River.

[i] Accurate counts not available.

Creeks and along the Lake Washington and Lake Sammamish shorelines (Fig. 22).

Project assessment

Five years after the first transplant, 9,099 sockeye returned to the Issaquah Creek to spawn naturally in a watershed previously unutilized by anadromous sockeye. Electrophoretic studies conducted during the 1970s on the different sockeye populations in the Lake Washington system showed a good match only between the Baker River and the Cedar River runs. This indicated that the Cedar River run has indeed originated from the Baker River stock. All other sockeye stocks examined in the Lake Washington system (Bear Creek, Lake Washington, and Lake Sammamish stocks) are probably native fish or transplanted stocks hybridized with native fish.

The sockeye population in the Lake Washington system presently is being evaluated through pre-smolt estimates, and catch and escapement estimates.

Suggested reasons for transplant success

Donor/recipient combination

Lake Washington was historically famous for its kokanee production indicating that it could support the landlocked form of sockeye. Cedar River provided an extensive potential spawning area for sockeye adults, while Lakes Washington and Sammamish supplied large potential nursery areas for the sockeye juveniles. A physical diversion of Cedar River into Lake Washington achieved the necessary migration pathway for juveniles into that lake.

The Baker River donor stock in the Skagit system was relatively close, about 70 km from the receiving area, and also in the Puget Sound area. The orientation and length of the freshwater migration route were similar for the donor and receiving sites. Also, the donor sockeye may have been IHN-free and therefore well-suited for hatchery propagation.

Transplant techniques

The long-term transplant program conducted in 18 of the 28 years between 1935 and 1963 successfully maintained and strengthened the introduced run. After 1947, progeny of the transplants provided most of the hatchery broodstock used to supplement the run. The success of this transplant probably can also be attributed to the outplanting of a variety of juvenile stages including fry, fingerlings and yearlings. In addition, the release of juveniles in several locations throughout the Lake Washington watershed served to utilize available natural spawning areas more fully. Finally, the progressive eutrophication of Lake Washington in the 1950s and early 1960s probably stimulated sockeye production.

Weaknesses of the transplant program

The transplanted stock established itself relatively slowly over several decades, partly due to the low annual outplants (approximately 275,000 per year) and intermittent lapses in introductions. Rearing mortalities in hatcheries due to IHN prevented continued enhancement of the introduced stock during the 1970s. Although self-propagating, the introduced stock has a low recruitment rate of only about 1.5 returns per spawner compared to 4.0 returns per spawner for Fraser River sockeye. This is possibly due to flooding of the spawning area, fry mortality as indicated by high incidence of IHN virus, and heavy predation by hatchery-produced steelhead smolts (J. Ames, pers. comm.).

KOKANEE TRANSPLANTS

Kokanee is the resident freshwater form of sockeye salmon. The original distribution of kokanee was confined to a few lakes in USSR (C. Foote, pers. comm.), to northern Japan and to the west coast of North America from Alaska to Oregon and Idaho (Maher 1964; Nelson 1968). Through introduction, the range of kokanee has been extended south from Idaho to Colorado and California in the United States and from Hokkaido to Honshu in Japan; their eastern range has been extended from Montana to New England, including some of the Great Lakes (Ricker 1972). Kokanee can spawn in a wider variety of habitat than other salmon species and utilize both gravelly shore areas and tributary streams; they have a strong homing tendency to return to the site of release; they are landlocked and therefore not exposed to extensive straying and marine-related mortality; and show excellent survival of up to 29% from planting of "swim-up" fry directly into the lake (Maher 1964). Kokanee have been widely introduced into small and medium sized lakes in western North America to provide food for rainbow trout and to support a sport fishery in their own right (Maher 1964). Examples of successful kokanee transplants are given below in Appendices 18 to 21.

APPENDIX 18. KOKANEE TRANSPLANTS IN BRITISH COLUMBIA

Sources of information: Larkin 1954; J. Cartwright (pers. comm.); D. Smith (pers. comm.).

Synopsis

In British Columbia, a number of lakes have been successfully stocked with kokanee for sportfishing purposes and as forage fish for Kamloops trout. For example, in Jones Lake (Hope district) and Premier Lake (Cranbrook district), kokanee were originally introduced as forage fish for Kamloops trout, but subsequently expanded to support significant sport fisheries. Echo Lake near Lumby was stocked repeatedly in the early 1940s and presently maintains a good kokanee population. Stump, Vidette and Green Lakes, all within 100 km radius of Kamloops, were stocked successfully in the 1960s and 1970s. Vidette Lake was initially poisoned in the mid-to-late 1970s to remove coarse fish, then restocked with kokanee fry during three successive years. The result was a flourishing self-sustaining population. Stump and Green Lakes lack a natural spawning habitat and must be restocked annually to maintain the sport fishery. Stocking of British Columbia lakes with kokanee, primarily through egg transplants, is presently conducted as part of the Provincial Hatchery Program. Most of the donor broodstock for earlier and current transplants comes from Meadow Creek, located at the northern end of Kootenay Lake.

APPENDIX 19. KOKANEE TRANSPLANTS IN THE GREAT LAKES

Sources of information: Ricker and Loftus 1968; Parsons 1973.

Synopsis

Between 1950 and 1970, about 19 million kokanee were transplanted to the Great Lakes, primarily Lakes Ontario and Huron (Fig. 24). The transplants consisted of fry (74%), fingerlings (17%) and eggs (9%). Kokanee eggs transplanted to Lake Huron streams in 1964 and 1965 originated from British Columbia, Colorado, Montana and Washington (Fig. 24). Of the total transplants, survival was highest for fingerlings released in Lake Huron where spawning runs have developed in several streams.

APPENDIX 20. KOKANEE TRANSPLANTS IN LAKE KOOCANUSA, MONTANA

Sources of information: Anon 1984a; L. Siemens(pers. comm.).

Synopsis

In the late 1970s, a few hundred kokanee fingerlings which probably originated from the Okanagan River stock, were accidentally spilled from the Bull River trout hatchery near Cranbrook, B.C. into a small creek flowing into Lake Koocanusa (Fig. 25). This lake is an international reservoir formed behind Montana's Libby Dam. The introduced kokanee reproduced at a great rate and within about three cycles increased from several hundred to approximately 1.4 million spawners in 1984. These fish presently are spawning in numerous tributaries of British Columbia and Montana, and are providing excellent angling opportunities. In 1984, about 4 million eggs were collected from natural spawners for hatchery rearing and outplanting to maintain the strength of the run.

The success of this accidental transplant is partly attributed to the absence in Lake Koocanusa of planktivorous fish which may have competed with kokanee for food.

APPENDIX 21. KOKANEE TRANSPLANTS IN CALIFORNIA

Sources of information: Curtis and Fraser 1948; Fraser and Pollitt 1951;Kimsey 1951; Tuma 1962.

Synopsis

The kokanee were first transplanted to California waters in 1941. This species was selected for introduction because of its popularity in parts of the northwest and its planktivorous food habit which made it suitable for stocking of reservoirs where water fluctuations resulted in poor production of benthic and littoral food. The earliest successful transplant occurred in the Salt Springs Reservoir where 67,000 fingerlings (1 g) were outplanted in July 1941; the eggs were imported from Idaho and hatched in a California facility near Sonora. In the fall of 1943, over 3,000 fish were captured in seines in the reservoir indicating a survival of well over 5%. Between 1944 and 1947, Strawberry Lake received 489,000 kokanee juveniles ranging in size from 0.1-1.3 g; the eggs for the transplant came from Washington and Montana. By 1946, large catches of up to 25 cm kokanee were reported in this lake. Washington and Montana also supplied kokanee eggs for transplants into Donner Lake which between 1944 and 1947 received 257,000 juveniles ranging in size from 0.1-0.6g. This stocking program produced natural spawning populations since 1946 and a good sport fishery with adults in a 30-40 cm range.

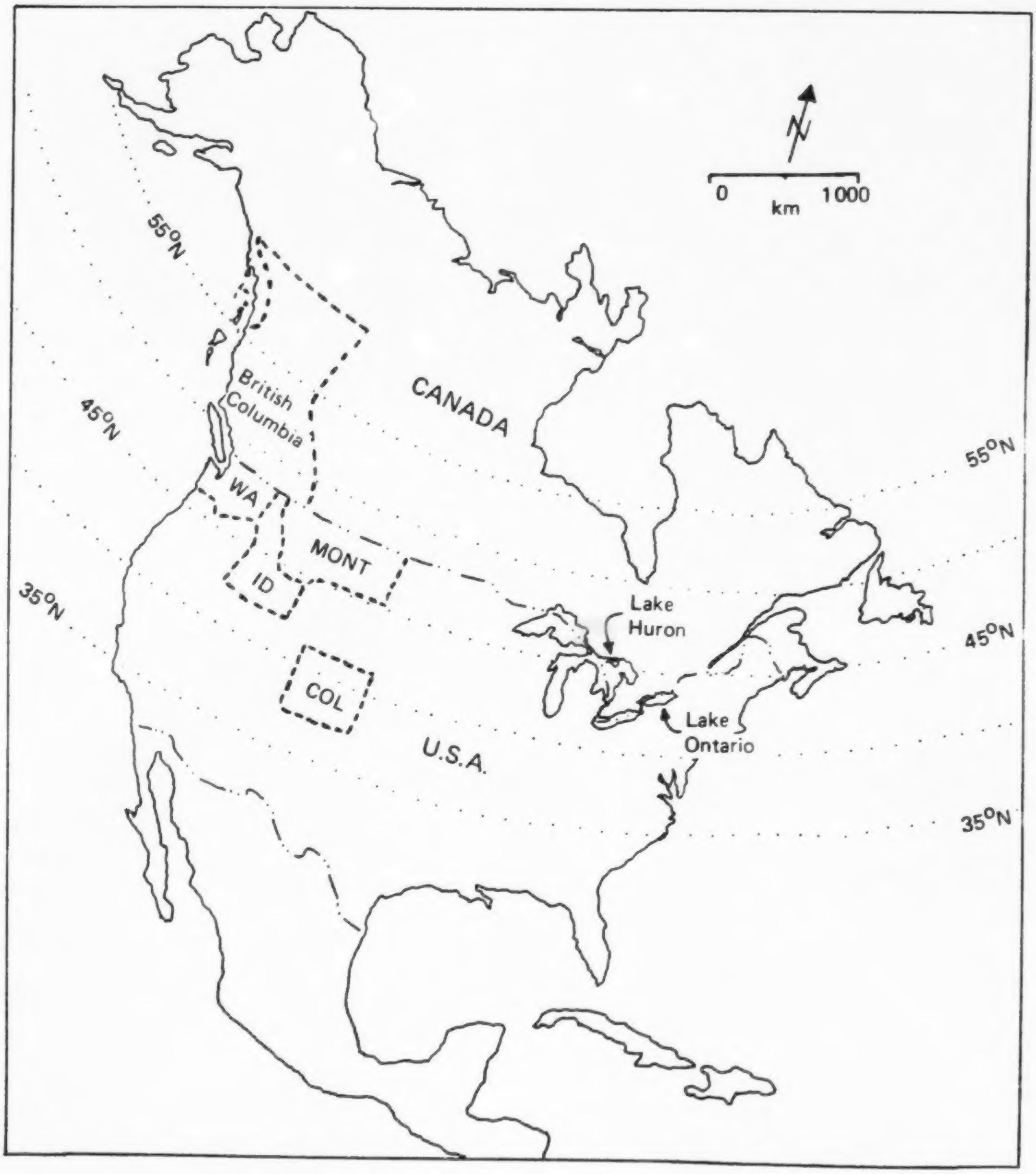

0
km
1000
N
55°N
45°N
35°N
British Columbia
CANADA
WA
ID
MONT
COL
U.S.A.
Lake Huron
Lake Ontario
55°N
45°N
35°N

Fig. 24. Location of British Columbia, Washington, Idaho, Montana and Colorado relative to Huron and Ontario Lakes.

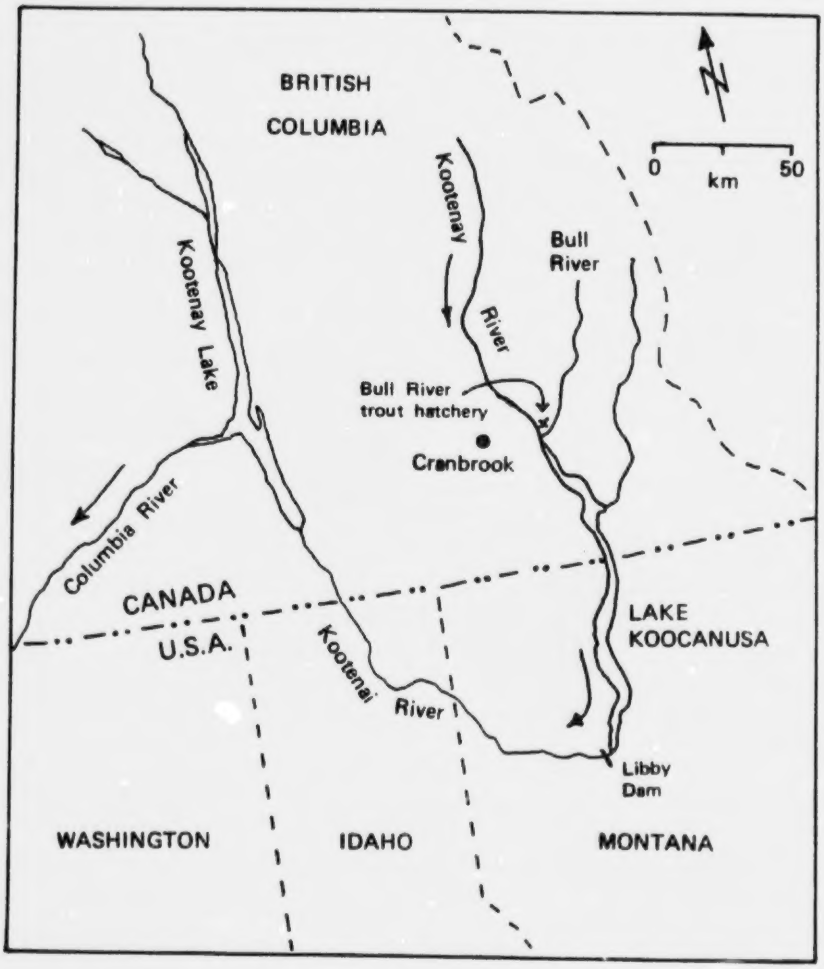

BRITISH
COLUMBIA
0
km
50
Kootenay Lake
Kootenay
River
Bull
River
Bull River
trout hatchery
Cranbrook
Columbia River
CANADA
U.S.A.
Kootenai
River
LAKE
KOOCANUSA
Libby
Dam
WASHINGTON
IDAHO
MONTANA

Fig. 25. Location of Lake Koocanusa in Montana (arrows indicate direction of flow).

In addition to the stocked lakes and reservoirs, a number of accidental releases of juveniles from hatcheries and from stocked systems have resulted in several self-perpetuating runs. For example, Lake Tahoe produced its first returning spawners from an accidental escapement from Tahoe Hatchery in 1944. Subsequent active stocking of Lake Tahoe with kokanee included planting of 90,000 fingerlings in 1949 and 613,500 in 1950. Juveniles were outplanted directly into the lake and into suitable tributary streams utilizing trucks and barges to ensure maximum distribution of fish into suitable spawning areas.

Introduced kokanee grow rapidly in California lakes and are considered more as a sporting fish than a forage species. The largely successful introductions conducted during the 1940s and 1950s generally utilized a stocking rate of 500-600 fry/ha at 0.2 g .

COHO TRANSPLANTS

Among Pacific salmon, coho are probably the most suitable species for successful transplanting. Brannon et al. (1982) observed that coho are a very plastic species as indicated by their wide geographical and ecological distribution. Compared to other Pacific salmon species, coho are also more disease-resistant and are readily propagated in hatcheries (Wood 1974). Coho can be readily imprinted to a freshwater release site (Lister et al. 1981) and appear to be very adaptable to seawater rearing (Anon. 1975). In addition, Harache (1979) observed that compared to other anadromous Pacific salmon species, coho have a shorter ocean grazing range and are therefore less likely to stray extensively during ocean migration. Some of the successful coho transplants are summarized below in Appendices 22 to 24.

APPENDIX 22. COHO TRANSPLANTS IN THE GREAT LAKES

Sources of information: Aron and Smith 1971; Parsons 1973; Carl 1982; Withler 1982.

Synopsis

Between 1966 and 1969, 10.5 million coho were planted in the Great Lakes, with Lake Michigan receiving 65% of the releases. Donor stocks were primarily of Columbia River origin. An early timing Alaskan stock was also used to provide an early fishery in August. Coho were reared for 16 mo at Great Lakes hatcheries and released into selected tributaries at about 25 g in lots of approximately 90,000 smolts. Prior to release, fish were held for 2-8 wk at the recipient stream for imprinting.

These coho transplants resulted in a successful sport fishery, with a 19% recovery in the sports catch during 1966 to 1970. Transplant success was highest in Lake Michigan, where approximately 251,600 adult coho were captured annually between 1966 and 1969. In 1970, anglers in Lake Michigan caught 576,000 coho weighing between 2.3 and 4.5 kg. This catch represented 12% of the coho smolt outplants made in 1969. By 1970, relatively large spawning runs of coho were observed in most of the tributaries of Lake Michigan where juvenile coho had been released. At present, releases of hatchery juveniles continue to supplement the coho sport fishery in the Great Lakes.

The success of coho transplants in the Great Lakes is attributed to an apparently good selection of donor stocks, favourable release sites and suitable planting techniques. The use of several donor stocks from the Columbia River provided a wide genetic base which probably facilitated the process of natural selection. The initial intensive infusion of coho through massive outplants favoured good adult production and helped establish natural runs quickly. The release of older and larger smolts, held for imprinting prior to release, probably resulted in improved survival and homing to streams. Finally, the absence of a marine phase in these landlocked populations may have reduced straying and eliminated marine-related mortality.

The high transplant success observed in Lake Michigan compared to the other Great Lakes may be attributed to several factors. They include the presence of a large number of suitable tributaries, appropriate temperature and oxygen regimes in Lake Michigan, a strong forage base consisting primarily of alewives, absence of competition by other large piscivorous species except for the introduced chinook, and control of predatory sea lampreys. Transplant success was considerably lower in Lakes Superior, Huron, Erie and Ontario partly due to lower abundance of forage species, eutrophication in Lake Erie, and in Lake Ontario , severe lamprey predation as well as poor homing to local streams.

APPENDIX 23. COHO TRANSPLANTS IN ALASKA

Source of information: Heard 1978.

Synopsis

Alaskan barrier lakes on Baranof Island are being stocked with coho fry to utilize them as nursery lakes. These lakes lack native coho populations since their upstream access is blocked by falls near the lake outlets. Nearby donor stocks are selected to reduce the genetic effect of straying on the wild populations. The stocking programs are evaluated for rearing survival through mark-recapture programs, and for fry growth, food habits, distribution and behavior. In three such lake studies, fry-to-smolt survival averaged 26 — 68% and smolt-to-adult survival averaged 4.6 —13.6%

APPENDIX 24. COHO TRANSPLANTS IN NEW HAMPSHIRE

Sources of information: Stolte 1974; Anon. 1975; FFI 1980.

Synopsis

Successful coho introductions into New Hampshire streams (Fig. 26) have resulted in the development of a popular saltwater sport fishery. Annual egg transplants commenced in 1967, using several lower Columbia River stocks and the Green River stock from Puget Sound. Note that these donor stocks are considerably more northerly in latitude than New Hampshire (Fig 26). Later transplants were supplemented with eggs from returning progeny of the introduced fish. In the initial 1967 to 1969 brood transplants, approximately 100,000 eggs were transported annually from donor streams. Juveniles were reared to 28-45 g and released in April as yearling smolts. Their estimated harvest ranged from 0.47% for 1968 brood to 1.26% for 1969 brood. Between 1969 and 1978, 80,000-186,000 coho smolts were released each year into New Hampshire coastal streams, primarily the Exeter and Lamprey Rivers which empty into Great Bay. Annual recoveries (sport fishery and escapement) from the early transplants

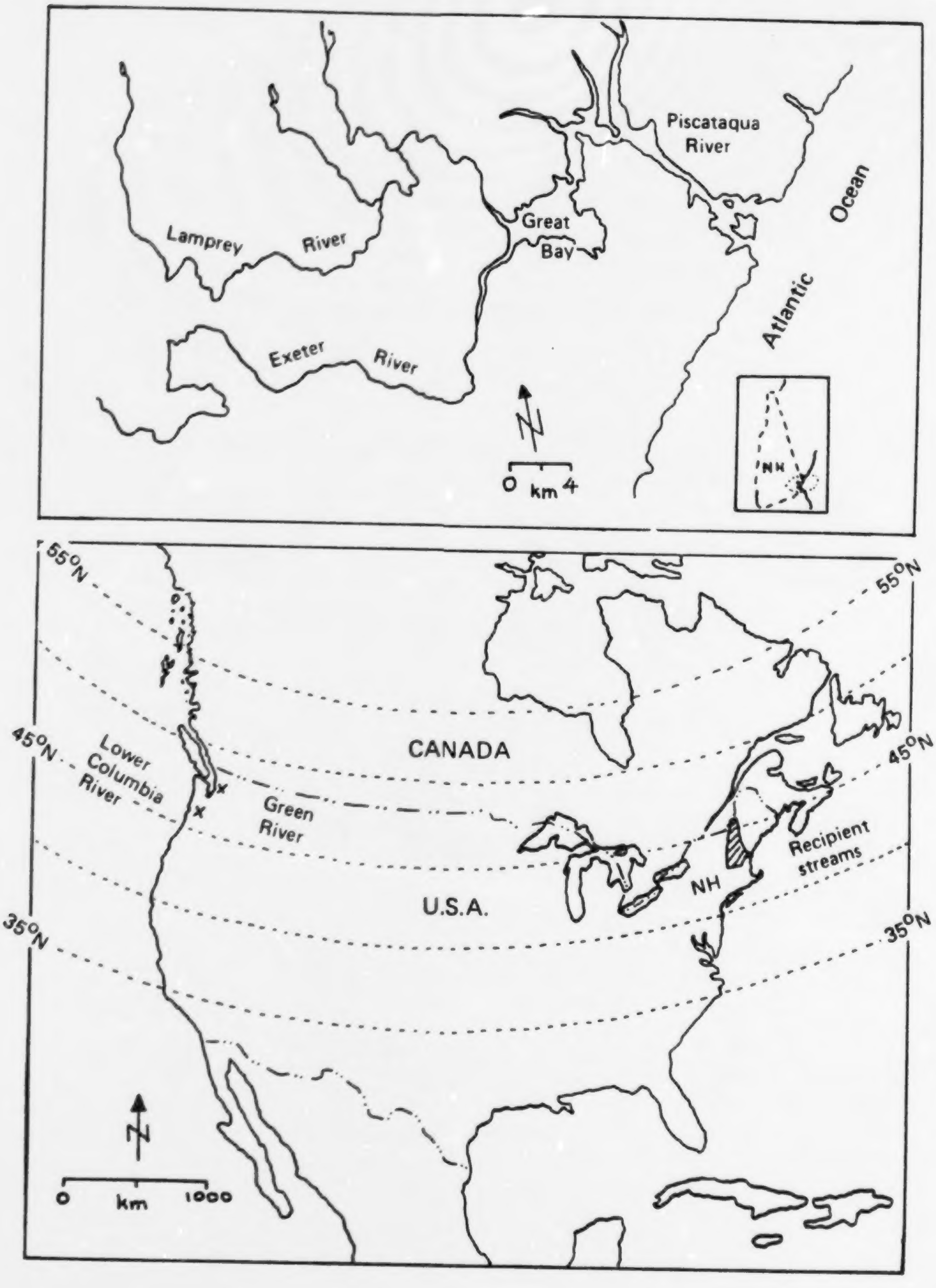

Piscataqua
River
Lamprey River
Great
Bay
Exeter River
Atlantic Ocean
0 km 4
NH
55°N
55°N
CANADA
45°N
Lower
Columbia
River
Green
River
45°N
NH
Recipient
streams
U.S.A.
35°N
35°N
0 km 1000

Fig. 26. The recipient streams, Lamprey and Exeter Rivers in New Hampshire (top; from Stolte 1974), and the relative location of New Hampshire and the donor streams, Green River and lower Columbia River on the Pacific coast (bottom).

were 1-3%. In 1972, about 2,700 adults were estimated to have returned to the Great Bay from a 1969 brood Green River transplant, giving a survival of 3.5%. Of this total, over 1,000 were caught by anglers. Returns increased for second and third generation smolts descended from the original transplants. The coho transplants in New Hampshire are sustained entirely by hatcheries due to unfavourable freshwater conditions for natural reproduction, in particular the absence of appropriate spawning habitat in the coastal streams and very warm summer temperatures of up to 25°C.

PINK SALMON TRANSPLANTS

Pink salmon transplants generally have been very unsuccessful (Withler 1982). With a few exceptions such as the pink transplants into the Great Lakes, no substantial self-sustaining populations have been developed despite numerous attempts since the early 1900s to establish pink salmon in new regions or in missing year cycles (Neave 1965). However, many individual pink salmon transplanted as eggs have successfully completed the life cycle and homed accurately to the new environment. Neave (1965) listed several possible causes for failure to establish permanent populations. These include unsuitable donor/recipient combinations, lower viability of hatchery fish compared to wild fish, predation on transplanted salmon by other species, straying of adults, overfishing, and some unknown pre-existing factors that hinder development of off-year cycles. In addition, pink transplants may be particularly vulnerable because of their fairly rigid 2-yr age structure compared to other Pacific salmon (Thorpe 1980). As a result, an entire transplant race may be wiped out if a single year class perishes. Some examples of pink transplants are summarized below in Appendices 25 to 29.

APPENDIX 25. PINK TRANSPLANTS IN THE GREAT LAKES

Sources of information: Schumacher and Eddy 1960; Parsons 1973; Collins 1975; Kwain and Chappel 1978; Aro 1979; Kwain and Lawrie 1981; Emery 1981; Kwain 1982; Kwain and Kerr 1984.

Synopsis

In 1956, approximately 21,000 pink fingerlings were accidentally released from Port Arthur Hatchery into Thunder Bay of Lake Superior. These fish were imported as eggs from Skeena River, British Columbia, and were originally destined for Hudson Bay. No further plantings were conducted. First recoveries of natural spawners were made in the fall of 1959 in Lake Superior tributaries. By 1969, this species had completed six generations of natural reproduction in odd years (1959-69), and had spread throughout most of the Lake Superior tributaries, with some runs numbering up to 1,000 spawners. By 1979, some of these runs exceeded 10,000 fish and the species range extended into all of the other Great Lakes.

Except for a smaller size and absence of a marine phase, the Great Lakes pink salmon appear to be similar in all respects to the Pacific pink salmon. However, an intriguing development was noted in that in addition to the continuous expansion of the odd year population in the Great Lakes, a new even year run has developed without human manipulation, and by 1980, a strong even year population was reported in Lake Superior. Scale analysis suggested that these fish were generated from odd year pink salmon that matured in their third year. This possibiliity was confirmed by observations of 1-yr-old sexually mature precocious males and 3-yr-old females among the normal 2-yr-old populations in a single lake in a single year. This phenomenon demonstrates the considerable plasticity of the pink salmon life cycle in the new freshwater environment. The diversity of response is surprising given very limited donor numbers.

Presently, the populations of pink salmon in the Great Lakes account for millions of spawners. This species is becoming increasingly important in the lakes' commercial and angling fisheries. The success of this pink colonization is attributed to several factors including the brief 2-yr life cycle which may have assisted the adaptation process, the plasticity of the life cycle which enabled the development of both even and odd year spawning populations, the depressed state of predatory lake trout as well as of lake herring and alewives, both potential competitors during the early colonization period, and the absence of a marine phase which eliminated marine-related mortality and extensive straying.

In this transplant example, a single, relatively small planting resulted in a firmly established self-sustaining population of even and odd year landlocked pink salmon. The Great Lakes pink salmon are unique in that they not only established the world's only known self-sustaining landlocked population of this species, but have expanded and dispersed with extreme rapidity.

APPENDIX 26. PINK TRANSPLANTS IN NEWFOUNDLAND

Source of information: Lear 1975.

Synopsis

Between 1959 and 1966, approximately 15 million pink salmon eggs were transported from British Columbia to Newfoundland streams. The returns from this introduced population reached a maximum of 2,600 adults in 1967, but after several generations without further replenishment the run died off. Among other shortcomings, this transplant effort was probably not sufficiently intensive. Lear (1975) recommended a long-term committment of up to 10 years combined with large scale transplants of 10-15 million eggs each year to allow the developing populations to recover from years of unfavourable environmental conditions.

APPENDIX 27. PINK TRANSPLANTS IN PUGET SOUND

Sources of information: Neave 1965; Dept. Fish. Canada MS 1966.

Synopsis

In Puget Sound, 182,000 pink fingerlings were planted in 1953 into Finch Creek in Hood Canal, using the Dungeness River donor stock (Fig. 27). Thereafter, up to 1.8 million pink juveniles from odd year egg-takes were released from the Hood Canal hatchery located at Hoodsport (Fig. 27). The fish were reared for up to 3 mo, including a brief period of saltwater rearing at the hatchery prior to release, and released at 0.45-1.5 g. The annual returns averaged 2,500 adults in the last decade (1977-85) with a maximum of 6,600 adults reported in 1963. The Finch Creek odd year pink run is entirely hatchery-sustained with no adults allowed past the hatchery facility to avoid any conflicts between the hatchery operation at the stream mouth and wild fry

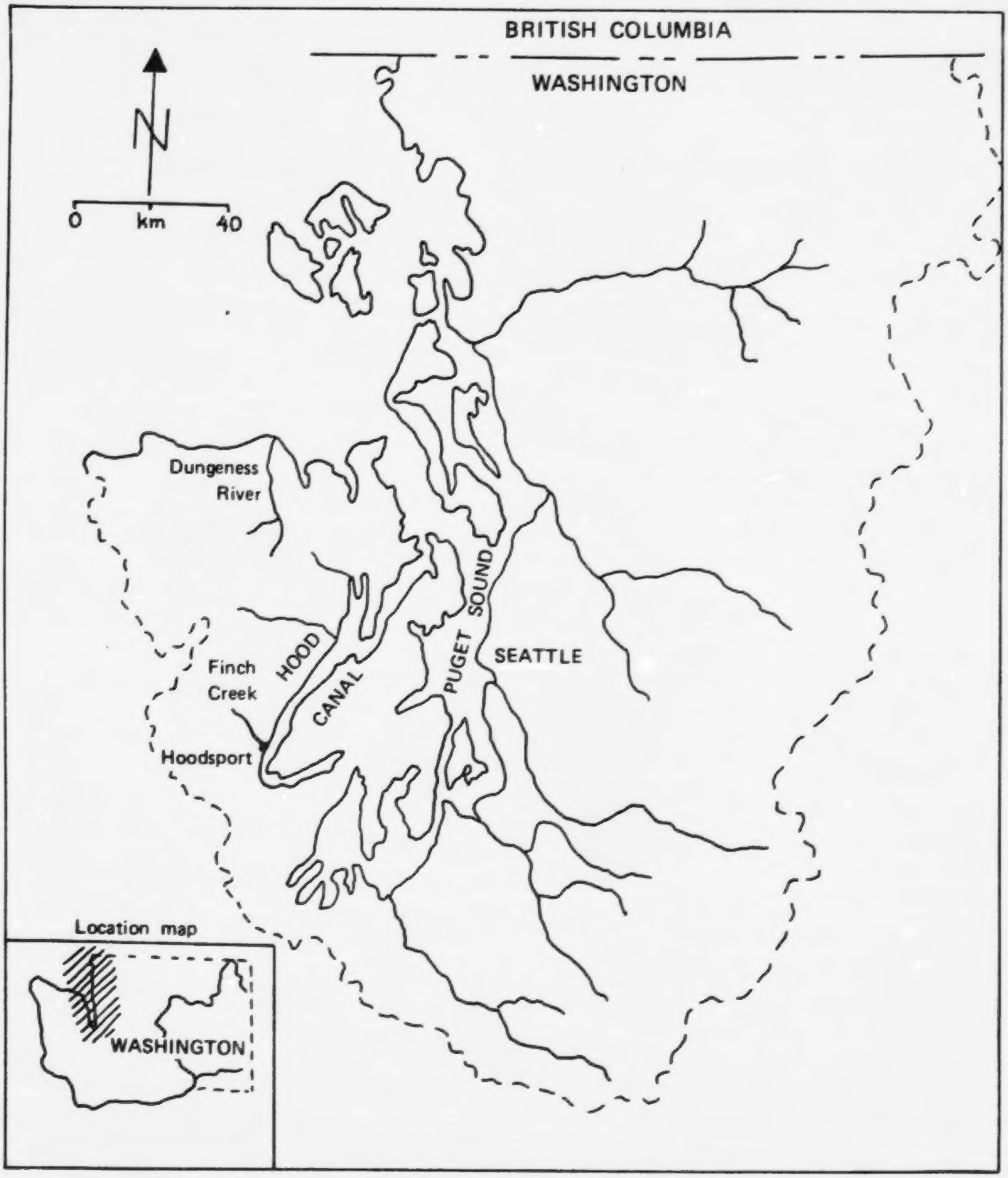

BRITISH COLUMBIA
WASHINGTON
N
0
km
40
Dungeness River
Finch Creek
Hoodsport
HOOD CANAL
PUGET SOUND
SEATTLE
Location map
WASHINGTON

Fig. 27. Location of Dungeness River and Finch Creek in Puget Sound, Washington (from Lister et al. 1981).

migrations. In this transplant, the donor and recipient systems are located about 120 km apart, and are within or close to the Puget Sound region. The hatchery broodstock is supplied entirely by the successfully returning transplant progeny.

APPENDIX 28. PINK TRANSPLANTS IN MAINE

Sources of information: Neave 1965; Thorpe 1980.

Synopsis

Approximately 29 million pink fry and 0.6 million pink fingerlings were released in Maine between 1905 and 1925 using donor stocks from Washington and Alaska (Fig. 28). Natural runs became established in the 1920s and several generations spawned in the Maine rivers. However, these runs were not supported with additional transplants and eventually died off, largely due to extensive dam construction in the area.

APPENDIX 29. PINK TRANSPLANTS IN KOLA PENINSULA

Sources of information: Neave 1965; Thorpe 1980; Withler 1982; Persov et al. 1984.

Synopsis

Odd year pink salmon runs were developed in the Barents and White Sea basins during the 1960s and 1970s when USSR hatcheries released about 200 million pink juveniles into the rivers of the Kola Peninsula and the Arkhangel'sk district in northeastern USSR (Fig. 29). The original donor stocks were transported from the far east regions of Sakhalin and Kamchatka (Fig. 29) starting in 1958. The present production from these partially self-propagating transplants is attributed largely to the sustained, large-scale transplants and the use of early-spawning donor stocks, whose eggs are sufficiently advanced in development to withstand the severe seasonal temperature drops during late fall in the receiving regions.

Due to severe stream freeze-up during winter in the receiving region and unstable freshwater and marine conditions, natural reproduction alone cannot sustain the introduced pink populations. Therefore, intensive programs are being developed to facilitate acclimation and create stable spawning populations. The strategy includes massive and regulated forms of reproduction including hormonal treatments to compensate for ineffective natural reproduction; the artificial selection of eggs from early-maturing local spawners in order to hasten the formation of an early- spawning populations, essential for the survival of eggs given the long and harsh winter conditions; and the release of advanced fry from thermoregulated hatcheries to increase survival.

By artificially manipulating the spawning, incubation and rearing phases of introduced fish, and by producing annual massive releases of fit juveniles during periods of abundant food supply and low predator numbers, a continuous and accelerated acclimation is expected. Without such artificial aid, USSR scientists believe that the process of natural selection in the Kola Peninsula transplants may be severely disrupted by climatic events such as a very severe winter.

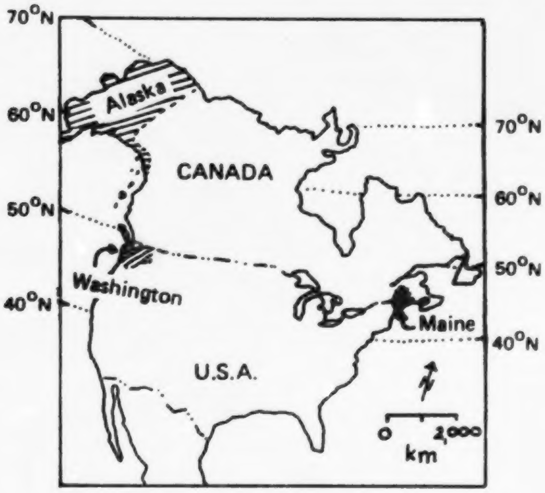

70°N
60°N
50°N
40°N
Alaska
CANADA
Washington
Maine
U.S.A.
70°N
60°N
50°N
40°N
0
2000
km

Fig. 28. Location of Alaska, Washington and Maine states.

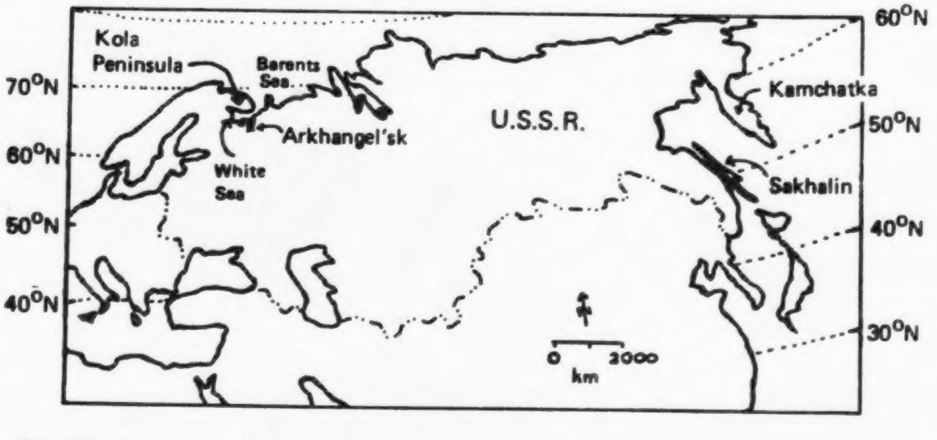

Kola
Peninsula
Barents
Sea
Arkhangel'sk
White
Sea
U.S.S.R.
Kamchatka
Sakhalin
70°N
60°N
50°N
40°N
60°N
50°N
40°N
30°N
0
2000
km

Fig. 29. Location of Kola Peninsula, Kamchatka and Sakhalin in U.S.S.R.

ATLANTIC SALMON TRANSPLANTS

APPENDIX 30. GENERAL

Sources of information: Thorpe 1980; FFI 1981a,b; 1984f,g; 1985a; Saunders 1981; Anon. 1984b.

Synopsis

Hatchery-reared Atlantic salmon have been transplanted extensively in North America, particularly in the Maritime provinces and in Maine, in an effort to colonize barren areas and rebuild decimated stocks. Often, however, no natural breeding population has developed even where several donor stocks were used to increase genotype diversity, and a variety of hatchery products were outplanted (fry, parr and smolts). Such "unsuccessful" transplants had to be maintained with hatchery assistance using the surviving returns for broodstock. Atlantic salmon have been also widely propagated through ocean farming in Norway and Scotland, and ocean ranching in Iceland and the Faroe Islands. Adult returns of up to 10% have been reported in Scotland.

Some of the techniques used for successful propagation of Atlantic salmon in transplant programs include close matching of physical environments of donor and recipient systems, production of healthy smolts to ensure high marine survival, release of a variety of life history stages including swim-up fry, smolts and adults, imprinting of juveniles for up to 6 wk at release sites, and practising delayed releases from seawater cages to promote a more local ocean distribution to enhance the local fishery. Examples of successful Atlantic salmon transplants are detailed below in Appendices 31 to 36.

APPENDIX 31. ATLANTIC SALMON TRANSPLANTS IN NEWFOUNDLAND

Source of information: O'Connell et al. 1983.

Synopsis

Historically, less than 10% of the Exploits River watershed in Newfoundland (Fig. 30) was available to anadromous Atlantic salmon due to the presence of natural and industrial barriers. Annual planting of the Exploits River with Atlantic salmon began in 1967. Adies Stream, located on the west coast of Newfoundland (Fig. 30), was the closest available source of surplus eggs and was selected as the initial donor stock. After 1974, broodstock was collected from Great Rattling Brook and at Grand Falls in the lower Exploits River (Fig. 30). The latter populations had by this time become sufficiently developed to provide a more local and better adapted broodstock for the upstream transplants.

Adults were spawned artificially and the eggs incubated in an artificial spawning channel and in upwelling incubation boxes located on a tributary in the middle Exploits River watershed (Fig. 30). Unfed fry were dispersed at about 400 m intervals by helicopter into predetermined stream areas with prime rearing habitat. Between 1968 and 1975, about 270,000 swim-up fry were stocked annually in Noel Paul's Brook where the incubation facility was located (Fig. 31). Between 1976 and 1980, the transplant program was expanded and approximately 1.4 million fry were stocked annually in various additional tributaries of the middle Exploits River. As a result of this expansion, adult

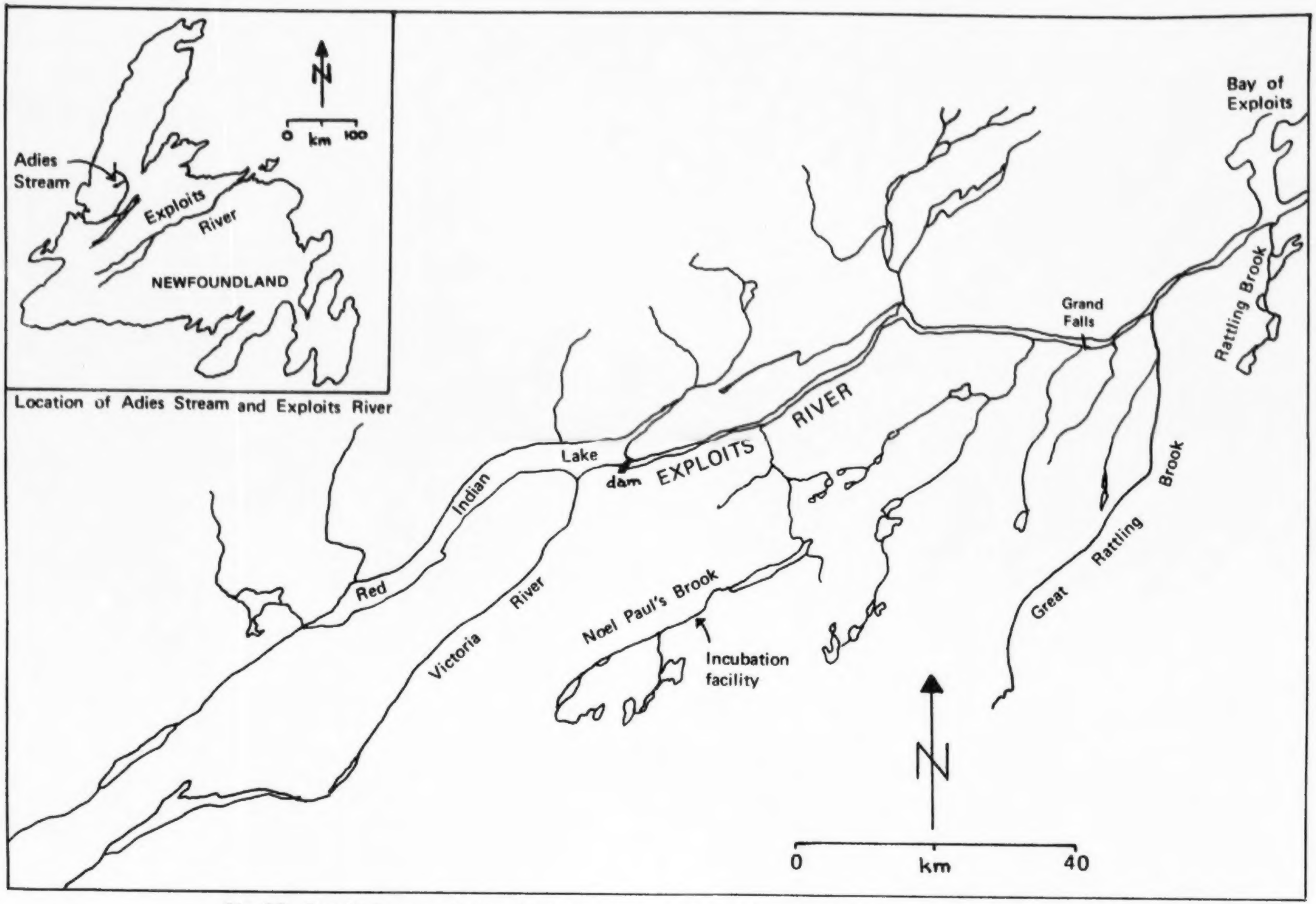

Adies Stream
Exploits
River
NEWFOUNDLAND
0 km 100
N
Location of Adies Stream and Exploits River
Bay of Exploits
Rattling Brook
Grand Falls
Great Rattling Brook
RIVER
EXPLOITS
Lake
dam
Indian
Red
Victoria River
Noel Paul's Brook
Incubation facility
N
0
km
40

Fig. 30. Detailed map of the Exploits River system (from O'Connell et al. 1983).

escapements increased from 64-340 fish in the early stocking program to 2,388-4,022 fish during later years.

The Adies donor stock used initially showed poorer returns compared to the more local donor stocks used later in the program. This was attributed in part to the different orientation of the sea entry routes and freshwater routes in the donor and recipient systems (Fig. 30), as well as the better environmental adaptation of the more local donor stocks compared to the Adies stock.

APPENDIX 32. ATLANTIC SALMON TRANSPLANTS IN NEW BRUNSWICK AND NOVA SCOTIA

Sources of information: Gray and Cameron 1980; R. Gray (pers. comm.).

Synopsis

Atlantic salmon stocking programs have been carried out in several Nova Scotia and New Brunswick salmon streams which were previously inaccessible or severely polluted. The transplants have been generally successful. For example, the LeHave River which between 1971 and 1979 received annually approximately 14,000-131,000 juveniles from Medway River located about 50 km away, showed an increase in escapement at the fishway from 6 adults in 1973 to 3,500 adults in 1981. Recent survival to escapement rates to the LeHave River averaged 1-2%.

A multi-disciplinary approach was used which simultaneously optimized strategies for donor selection, hatchery rearing and juvenile stocking. Starting in the early 1970s, each of the selected streams generally received approximately 20,000-60,000 juveniles annually between April and June. Release stages included 0+ fry, 0+ parr, 1+ parr, 1+ smolts and 2+ smolts.

Donor stocks were selected or genetically suitable broodstock strains were developed specifically for each enhancement project using donor streams with similar physical, chemical and environmental characteristics as the recipient site, and located geographically close to that site. This selection process served to increase chances that donor stocks would be biologically adapted to conditions in the new system and that migration routes and run timing would be suitable. Initially, different genetic stocks were tagged to determine which would provide maximum benefits for the project. In some cases, as in the transplants to LeHave River, fitness of the stock was maintained through routine crossing of the hatchery adults with the residual wild stocks in that river. Early run segments of the donor stocks were utilized in order to enhance the more attractive and profitable for tourism summer sport fishery compared to the fall/winter fishery.

An appropriate hatchery rearing strategy was developed for each system to produce healthy, high-survival juveniles for stocking. Fry and parr were released in appropriate habitat types in accordance with predetermined rearing and spawning capacities to increase juvenile survival and maximize habitat utilization. Dispersed stocking of juveniles throughout each watershed was aimed at reducing predation and inter- and intra- specific competition. A variety of juvenile stages were generally released in each river. Smolts were usually released during the normal period of smolt migration. Stocking projects were assessed through the release of tagged groups to evaluate the performance of selected genetic stocks, different salmon diets, different time and size at release, and other variables.

APPENDIX 33. ATLANTIC SALMON TRANSPLANTS IN MAINE

Source of information: K. Beland (pers. comm.).

Synopsis

Atlantic salmon runs in Maine were decimated through heavy industrialization and had declined from historical escapements of 0.25-1 million fish to only several hundred by the 1940s. Subsequent continuous annual stocking of juveniles into the Maine rivers has resulted in moderate success, with escapements of 5,000-10,000 fish reported in the 1980s.

Several major transplant strategies were used for stocking Atlantic salmon in Maine. The donor stock was created artificially using two local self-sustaining populations taken from the same geographical area (earlier transplants using more distant donor stocks were less successful). Only the returning progeny of transplants were used for broodstock since these probably represented the best-adapted fish to the new environment. A variety of hatchery-produced juvenile stages such as emergent fry, 1+ parr and smolts were transplanted annually throughout the watersheds using helicopters and trucks. Adult transplants were also carried out. The success of these transplants is difficult to assess since no marking programs were conducted to differentiate the wild from stocked adult returns.

APPENDIX 34. ATLANTIC SALMON TRANSPLANTS IN ICELAND

Source of information: Isaksson et al. 1978.

Strategies

Hatchery-produced Atlantic salmon smolts are being stocked in barren streams in Iceland. The smolts are artificially propagated due to unsuitable flows and cold water temperatures in the receiving streams. In recent experiments conducted in 1975 and 1977 in several Icelandic rivers, smolts were reared before their seaward migration for 2-4 wk in special release ponds adjacent to the recipient streams and supplied with natural river water. Two to four times greater adult return and lower straying were obtained for these releases, compared to direct releases into streams. Based on this evidence, pond releases of Atlantic salmon smolts will replace direct releases into the barren rivers to improve survival and homing of transplants.

APPENDIX 35. ATLANTIC SALMON TRANSPLANTS IN THE FAROE ISLANDS

Source of information: FFI 1984d.

Synopsis

Historically, rivers on the Faroe Islands, located in the North Atlantic between Iceland and Scotland (Fig. 31), probably supported Atlantic salmon runs but these were terminated centuries ago. Between 1947 and 1963, approximately 20,000 Atlantic salmon fry were imported each year over an 8-yr period from an Icelandic river near Reykjavik (Fig. 31) and released into Faroe Islands rivers. These small plantings, using a northern donor stock, finally resulted in the first successful returns in 1962. In 1963, the first hatchery was built on the Faroe Islands to continue stocking the local streams with "Faroese" salmon fry. Some 150,000-200,000 fry are stocked each year using the returning progeny as broodstock. To date, natural spawning runs of Atlantic salmon have been established in five rivers.

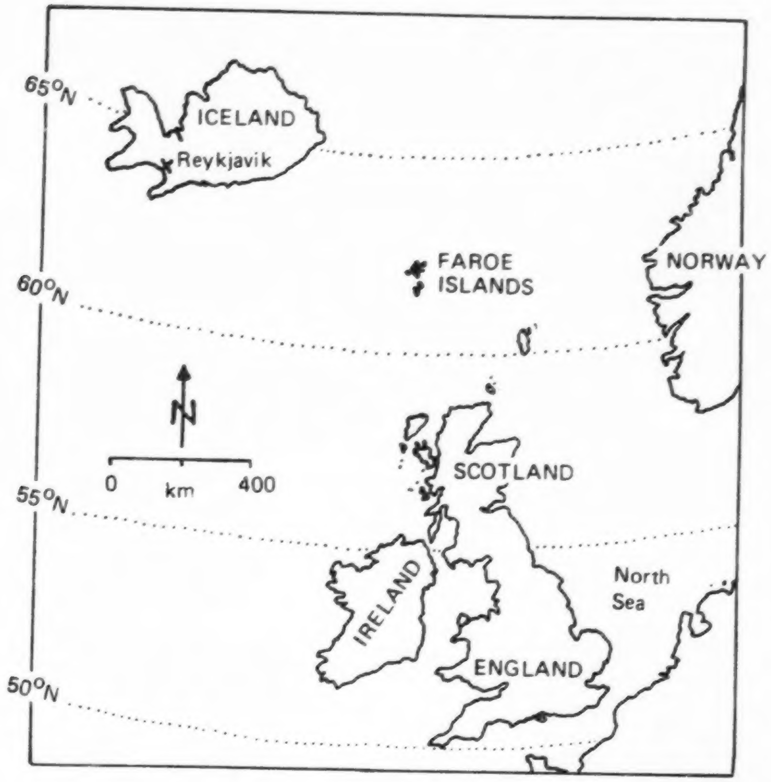

65°N
ICELAND
Reykjavik
FAROE ISLANDS
NORWAY
60°N
0 km 400
55°N
SCOTLAND
IRELAND
North Sea
ENGLAND
50°N

Fig. 31. Location of the Faroe Islands.

APPENDIX 36. ATLANTIC SALMON TRANSPLANTS IN ARGENTINA

Source of information: FFI 1978.

Synopsis

In 1935 and 1937, Atlantic salmon eggs were transplanted into Lago Yehuin located in Tierra del Fuego in the extreme south of Argentina (Fig. 32). The donor stock was hatchery-propagated, landlocked Atlantic salmon from Sebago Lake in Maine. Today, a self-sustaining population of landlocked Atlantic salmon is thriving in Lago Yehuin and in the nearby lakes and rivers of Tierra del Fuego. The latitudes of the donor and receiver sites were closely matched in this distant transplant.

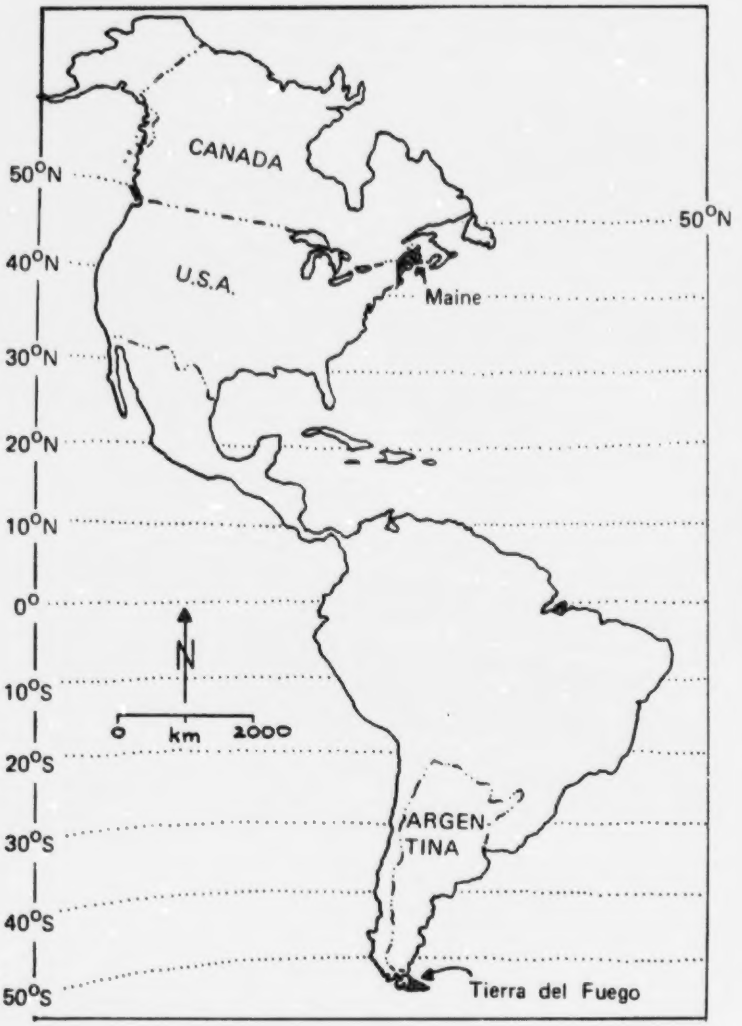

CANADA
U.S.A.
Maine
ARGEN-
TINA
Tierra del Fuego
50°N
40°N
30°N
20°N
10°N
0°
10°S
20°S
30°S
40°S
50°S
50°N
N
0 km 2000

Fig. 32. Location of Tierra del Fuego in Argentina and State of Maine in U.S.A.